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THE BRITISH JOURNAL OF METALS

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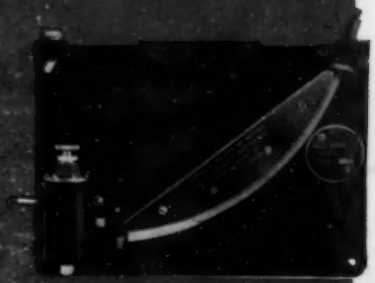

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The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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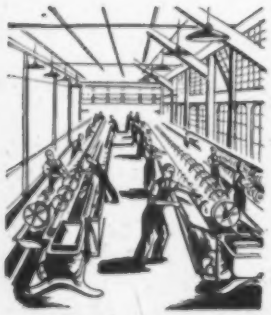

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DECEMBER, 1942 VOL. XXVII. No. 158

Development of Aluminium Alloys

By J. Towns Robinson
(*Technical Superintendent*, High Duty Alloys, Ltd.)

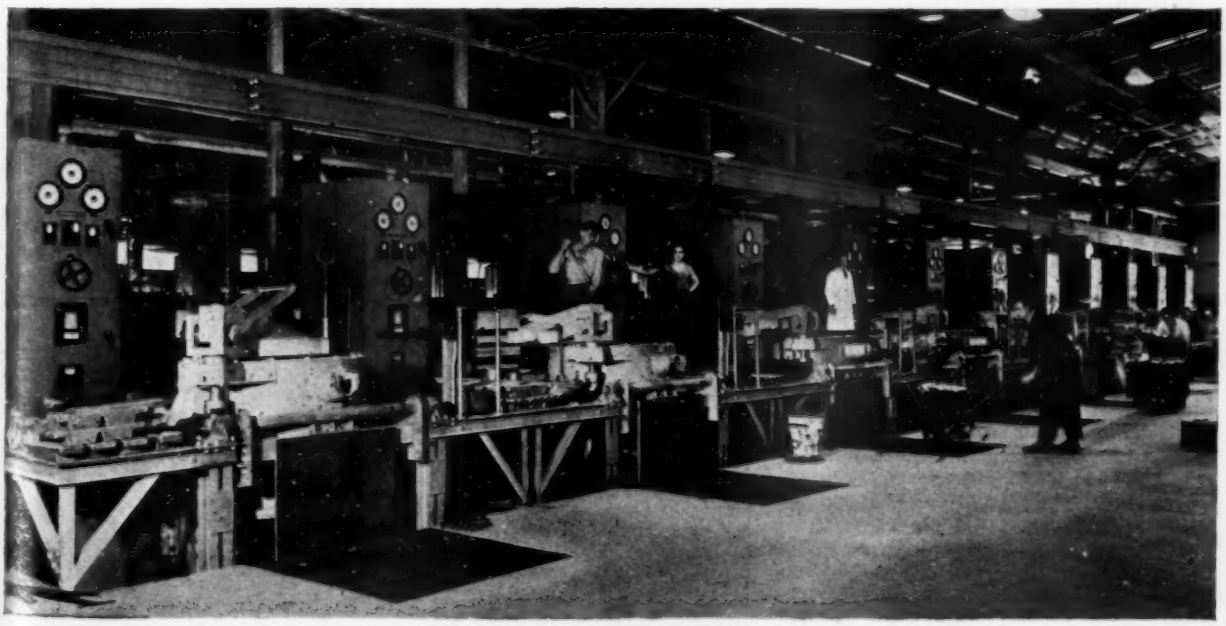
The largest demand on aluminium is in aircraft construction, both for engine parts, including propellers, and airframe construction. For engine manufacture, especially for use in bomber planes, the amount of aluminium consumed per engine averages about 1,000 lb.; but naval craft, too, are consuming a considerable amount. Progress in both fields has been made possible by improved technique in the production of various components, but it has been dependent on the production of suitable alloys.

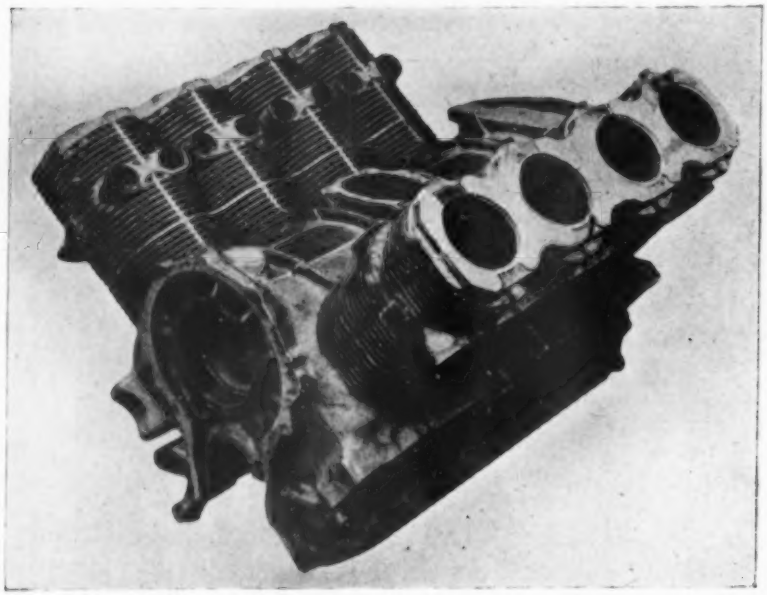
WHEN reviewing the progress of aluminium alloys it is interesting to go back in history to the last Great War of 1914–18 and note its effects on their progress, as this really marked the beginning of a new era in their development. Their characteristics and obvious great advantages had been but sparingly investigated from a scientific angle, particularly by the individual companies concerned in their manufacture. In a national sense very little research had been done except at the National Physical Laboratory, who must be given great credit and praise for their earlier work on the casting alloys, and particularly for their development of the well-known "Y" alloy. Even then it was some years later that "Y" alloy was actually taken up as a commercial enterprise, and its characteristics utilised to the full advantage in both cast and wrought forms.

The benefits to be derived from what one may term individual or commercial research in the aluminium alloy industry could only be envisaged by very few people in those days, and in the absence of any serious fundamental research by scientific institutions progress was naturally slow, and we were loth to become aluminium-minded. It therefore needed a stage in history such as the Great War and urgent necessity for aviation, both for combatant and non-combatant purposes, to supply the urge and effort to utilise and improve aluminium alloys. Full use was made by the Germans in the last war of the rigidity and lightness of aluminium alloys in the design and fabrication of the then famous "Zeppelin" aircraft by the employment of extruded and built-up sections for the frame structure and castings for the main engine.

I well remember the great interest that was displayed in obtaining and analysing and testing light alloy sections from crashed aircraft, and some very useful and valuable information was obtained from this source. It was obvious that the Germans were making good use of their experience and knowledge of their "Duralumin" type of alloy in the form of extruded sections, and some of these were of excellent quality. There was no doubt that in this particular form this alloy was outstanding, and there was nothing to equal it in wrought forms until "Y" alloy came into the field. Apart from these two alloys the other alloys in general had few virtues other than their intrinsic lightness, and were of comparatively low strength. The old "L"

A modern foundry, equipped with high-frequency induction furnaces, engaged in the production of aluminium alloys in Great Britain.





Cylinder block casting in Hiduminium R.R. 50. The cylinder barrels are cast integral.

type of casting alloys, such as L 5, L 8 and L 11, served a certain useful purpose and existed until comparatively modern times, but unfortunately they were very often badly fabricated. The 12% silicon-aluminium alloys, or "Alpax" type, had probably the best reputation, and are still in favour to-day after various modifications have been made to composition to give additional strength.

The period between 1920 and 1930 saw a gradual building up in powers and reliability in aviation which demanded something more from the aluminium alloys than mere lightness. The casting alloys then available were used in increasing quantities, and very considerable improvements were achieved in establishing the necessary forging or working technique on "Dural" and "Y" alloys. As a result of this knowledge greater applications were found on aircraft in the form of stampings and extruded sections in the replacement of steel. The advance in the scientific knowledge of the working properties of these alloys also resulted in a more important and fundamental change in policy, which was demanded by the progress of aviation. That change was the gradual replacement of castings by forgings and stampings which resulted in higher strength components, and hence much longer service conditions without overhaul or replacement. I think we can rightly claim the credit of being largely responsible for this "Stage" and also the success of its adoption by most of the European powers, and there is no doubt that it had a tremendous influence on the present standard of aviation. The successful results gained during this transition period although of far-reaching importance, were short-lived because industry was very soon crying out for stronger and better alloys.

For some time previous, the demand for better alloys had occupied the thoughts and efforts of certain scientific workers. The efforts of these workers were amply rewarded when, in 1930, specifications were published for the Hiduminium R.R. alloys and the present famous Merlin aero engine undoubtedly owes its *par excellence* to the creation of this group of alloys. The characteristics of these alloys are too well known to be repeated here, and their advent was soon the beginning of a period of keen competition by the super-Durals and the copper-aluminium series, DTD 298 and 304, in what is termed high-strength casting and forging alloys.

Intensive research and development of working technique has created an enormous increase in the applications of these high-strength alloys in all branches of industry.

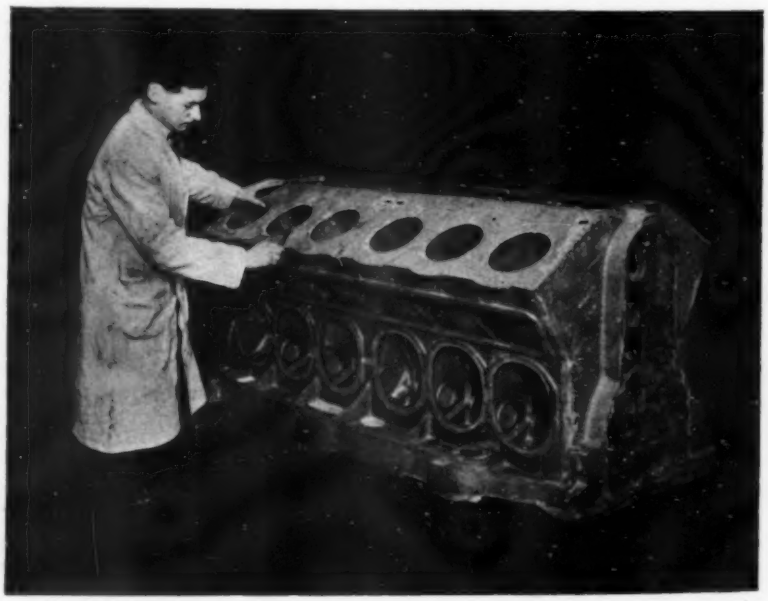
Taking the casting alloys first, we find that Hiduminium R.R. 50 has retained its popularity and is still the most extensively used for medium-strength purposes, and has given remarkable consistency, even under conditions of stressing to its maximum limit. There is some property which this alloy possesses apart from its medium strength which has probably as yet been undefined, which enables it to function under service stressing to a much higher ratio than any of the stronger alloys. This fact has been proved on such components as crankcases, for instance, in which the stressing has been stepped up enormously, with increased horse-power ratings, in recent designs of aero engines. On "cut-up" tests on large crankcases and cylinder blocks of dimensions and weights which would have been hitherto considered to be almost unaccessible the following tensile properties have been maintained in the actual castings in R.R. 50.

Ultimate stress	10—13 tons per sq. in.
Elongation	2·0—5·0% elongation.

These figures are easily double, or more, the strength which could be obtained on the old cast alloys, even with the intricacy of design which would not even have been contemplated. As an example of the trend of design, it can be stated that the cylinder block casting on one of our present aero engines in production at the present time has over 300 cores in it, and yet these castings can be made pressure tight without excessive scrap in R.R. 50.

High-strength casting alloys, such as DTD 298, 300 and 304, are of relatively new development, and experience of them in the production of large highly stressed present-day castings has been somewhat limited, although they have

Cylinder block and crankcase casting in Hiduminium R.R. 50 for naval craft.



been, and are being, successfully produced. They require specialised foundry technique and rigid scientific control therefore, naturally they cannot be handled successfully, and stability of production maintained, by any foundry which still uses the old rule-of-thumb methods; this, of course, does not detract from their usefulness. This class of alloy has very enhanced properties in the form of the standard test-bar figures for specification purposes, and designers have been greatly attracted by the high strength, and have utilised these properties to the full advantage in their designs by stressing up to the limit, and in fact endeavouring to replace stampings by castings. This policy has, unfortunately, produced, in some instances, disappointing results insomuch as the high test-bar figures have not been realised or reproduced in the actual castings. The fundamental features or characteristics of these alloys, as already mentioned, have not been duly appreciated in complete co-operation between the designer and the foundry. In fact, I think I may be permitted to say that this question has lately occupied the attention of one of our foundry associations in co-operation with one of our scientific institutions, and has caused some real headaches in attempting to define the term "castability" or casting characteristics of an alloy in an endeavour to assist the designer. It is hoped that in the very near future some very valuable information will be published on this subject.

I would like to add that in an article which I wrote for this journal five years ago I drew attention to the desirability of closer liaison between the designer, metallurgist and foundry, which is well worth repeating here: "The author stresses the need for co-operation between the designer and metallurgist, so that the application of each casting can be carefully studied and advantage taken of special characteristics of a particular alloy.

Results of "cut-up" tests on actual castings in DTD 298 and 304 alloys give an indication of the high strength which they are capable of giving if correctly handled in the foundry.

ALLOY TO SPECIFICATION DTD 298.

Aircraft Undercarriage Casting.		Similar Component.	
Ultimate Stress, Tons per sq. in.	Elongation, %	Ultimate Stress, Tons per sq. in.	Elongation, %
11·0 to 15·5	5 to 12	8 to 13	2 to 5
Heavy section. Radiograph showed freedom from shrinkage porosity.		Radiograph showed porosity.	fine shrinkage

AIRCRAFT UNDERCARRIAGE FORK CASTING.
ALLOY TO SPECIFICATION DTD 304.

Ultimate Stress, Tons per sq. in.	Elongation, %	Ultimate Stress, Tons per sq. in.	Elongation, %
12 to 17	2 to 4	9 to 13	0·5 to 1·5
Radiograph showed freedom from shrinkage porosity.		Radiograph showed considerable shrinkage porosity.	

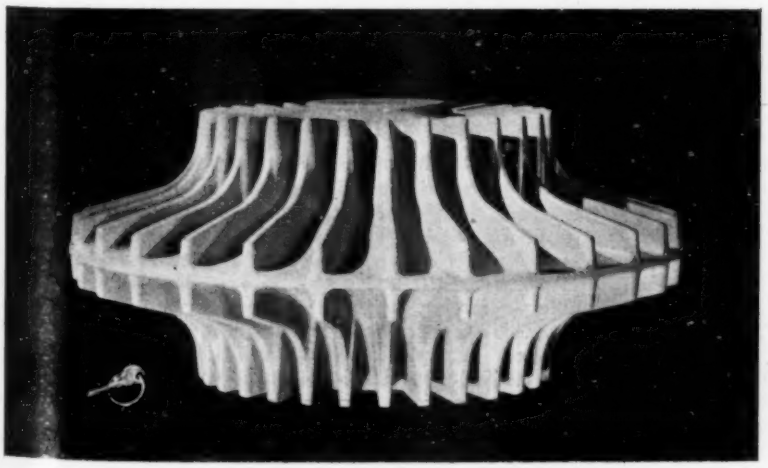
Apart from the high-strength casting alloys mentioned there has been no alloy evolved of any outstanding merit for some years, although there have been slight modifications made to the composition of a great number of alloys which have no doubt effected some improvement in their general quality. Our wider knowledge and experience, however, of the behaviour and the casting characteristics of the existing alloys has enabled us to put them to more exacting conditions of service and usefulness.

A 35,000 lb. Chambersburg drop hammer employed on the production of large forgings in aluminium alloy.

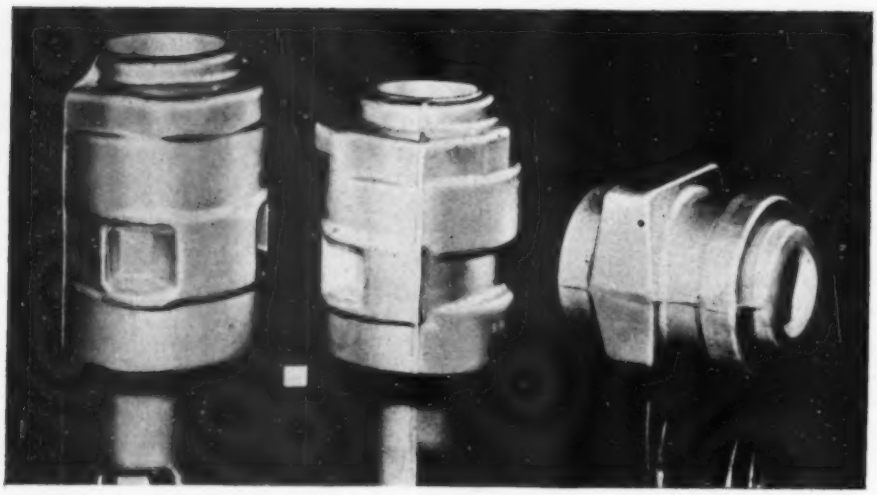
Although the development of the wrought alloys progressed almost on similar lines to the cast alloys, there was the difference that we had two well-established and excellent alloys in "Dural" and "Y."

When the Hiduminium R.R. wrought alloys, namely, R.R. 56 and R.R. 59, became available, the most striking improvement over the older alloys was the greatly increased proof-stress values, which immediately helped the designers to put up their stress ratings and a latitude for more intricate designs and weight reductions. The high strength of these alloys was combined with other highly advantageous characteristics, namely, the susceptibility to plastic deformation which aided in the fabrication of intricate components. The older alloys were certainly not easy to fabricate, and this feature has also been further exemplified in the experience of the development of the later high-strength wrought alloys. The R.R. 56 and R.R. 59 alloys are still to-day the most extensively used high-strength alloys, and have proved their reliability under most drastic service conditions experienced in modern aircraft.

Supercharger impeller stamping in Hiduminium R.R. 59. Components of this type are made up to 20 in. dia.



The reaction to the R.R. alloys was soon manifest in the appearance in specification form of the "Super-Dural," and in 1935 Specification DTD 280, covering the 24S and "Duralumin" G alloys, with a minimum proof stress of 18 tons per sq. in., ultimate stress, 28 tons per sq. in., and 10% elongation, after a solution heat-treatment only, which, particularly the proof stress, was superior to the standard "Dural." These properties were obtained by various alterations to the standard "Dural" chemical composition,



Some typical cylinder barrel stampings in Hiduminium R.R. 56 or R.R. 59 which require a special technique in ingot production and preliminary forging to ensure that uniform properties are obtained throughout. The weights of the three stampings are 65¼ lb., 46 lb. and 59 lb., resepctively, from left to right.

particularly the manganese and magnesium contents, were fairly readily obtained in the form of rolled or extruded bars and sections. They were, however, accompanied by certain manufacturing complications, such as reduced speed of extrusion, etc.; they were not maintained in forgings and stampings, and in this latter form progress was practically nil.

The period from 1936 to 1938 witnessed further alterations to the "Dural" compositions, and properties were specified equal to R.R. 56, with the minimum proof stress of 21 tons per sq. in., and these alloys are still in use at the present time, although as already mentioned they necessitated greatly improved manufacturing technique.

In 1937 Hiduminium R.R. 77 became available as the highest-strength alloy of the day, with a minimum proof stress of 27 tons per sq. in., ultimate stress 33 tons per sq. in., and 8% elongation, in the form of extruded sections, etc., to Specification DTD 363. Typical figures of present-day production in this alloy which can be maintained with the minimum of production difficulties are as follows:—

0·1% proof stress	35 tons per sq. in.
Ultimate stress	40 tons per sq. in.
Elongation	8—10%.

on extruded sections, even of fairly large dimensions such as wing-spar booms, etc.

R.R. 77 has, as one of its present alloying elements, up to 5% zinc, with additions of copper, magnesium and manganese, and although this percentage is much lower than the old zinc-aluminium alloys of ill repute, grave doubts have been expressed as to the wisdom of developing, this type of alloy in certain circles. It is interesting, therefore, to record that a similar type of alloy is being produced in America to Specification X 76S, and used for propeller blades in American aircraft. This type of alloy is somewhat difficult to forge and stamp with present technique, but in the form of pressings it can be successfully produced, even on such a large scale as aircraft propellers, with physical properties in the actual component in the order of 30 tons proof stress, 35 tons ultimate stress, and elongation values of 11% and over.

Following on R.R. 77 came another of the "Super-Durals," namely NA 26S, and Dural E, covered by Specification DTD 364, having specified properties of 28 tons per sq. in. proof stress, 30 tons per sq. in. ultimate stress, and 8% elongation for forgings and stampings, and extruded sections. Average figures on extruded sections in this alloy are 30 tons proof stress, 34 tons ultimate stress, and 10% elongation. The following table of mechanical properties of the older alloys in comparison with the latest wrought structural alloys strikingly illustrates the progress made in a comparatively short period of time in the high-strength alloys, and is in parallelism to the progress of aviation, and to which we owe our security and very existence to-day. I would here again quote from a previous article, written in 1935,* "I think it will be recognised that at no period in the history of the aluminium industry have the physical characteristics of the alloys borne such an important relation to the progress and development of international industry, and one is tempted to say the future destiny of nations than at the present time."

It must not be assumed that the high properties obtained on extruded sections in such alloys as DTD 364 can be reproduced in forgings and stampings in which the design and grain-flow characteristics have a predominating effect although under "ideal" conditions, in favour of these features the results are closely similar to specification.

Alloy and Specification.	0·1% Proof Stress, Tons/sq. in.	Ultimate Stress, Tons/sq. in.	Elongation % on 2 in.
"Y" alloy 4 L25	14	24	15
"Dural" 6 L1	15	25	15
2 L40 and DTD 130A, R.R. 56	21	27	10
DTD 364, NA 26S	26	30	8
DTD 364, R.R. 77	27	33	8

In American practice for general forgings and stampings, an alloy of the DTD 364 type is used, and for medium-strength requirements is given a solution heat-treatment only—equivalent to normal Duralumin, and for high-strength purposes it is fully heat-treated to conform approximately to DTD 364.

The development of new alloys of outstanding merits or or characteristics is becoming an exceedingly difficult task, although those responsible for research development are fully conscious to the position, and every possible field is being explored. This situation can be readily understood when one considers the enormous progress made in the quality of these alloys in a relatively short period of time. Maybe this position has been a blessing in disguise, because it has forced both the founder and the metallurgist to concentrate efforts on improved methods of fabrication.

There is no doubt that this factor has contributed more than any other to the present standard of quality, and the scientific knowledge gained has consolidated the industry as a whole. It has also proved an invaluable asset of national importance in enabling us to maintain under the difficulties of war-time conditions of material supplies, a standard of quality practically equal to pre-war conditions.

Although the hope of new alloys is somewhat remote in the near future, the outlook and prospects are extremely good, and we shall witness further improvements in manufacturing technique from the knowledge gained under present conditions. There is also no doubt that the light alloys will play an important part in the general reconstruction after the war in new applications which have as yet been unexplored; already the foundations are being laid for this new development.

* "The Effects of Thermic Treatment upon the Physical Properties of Aluminium Alloys." METALLURGIA, June, 1935.

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Metals and the War

METALS have long been essential in the successful prosecution of war, but never was the demand so great as in the present conflict, which has engulfed almost the whole world. Without easy access to metals and alloys a nation cannot survive in a highly mechanised war such as that in which we are engaged. Even with a preponderance of resources in this respect, unless the metals and alloys are converted into the various forms essential to the requirements of the various forces engaged in the conflict, at a speed commensurate with the state of emergency involved, victory, or even protection, is not assured. Apart from the numbers and fighting ability of the various forces engaged, therefore, the quantity and quality of metals and alloys available, and their speedy conversion into offensive and defensive weapons, are factors essential to victory.

We take this opportunity of extending to all Readers Sincere Good Wishes for Christmas and the coming New Year.

Although iron, copper, aluminium, zinc, lead and magnesium provide the basis for the bulk of these requirements, all metals are involved in some form or another—mainly in combination with other metals, because few are used in the pure state. The problem of obtaining adequate supplies is governed by the availability of the various metals, and they are distributed throughout the world by transport. In times of peace international trade throws open to all countries the world's resources in raw materials required to produce these metals, and the transport facilities are readily available. War, on the other hand, rudely disturbs normal commercial conditions, and when of such dimensions as at present prevail, substantial changes must be made to make full use of those minerals that are available so that production of high-quality metals can proceed with as little delay as possible.

Iron, which provides for the bulk of modern war requirements, is one of these basic materials, but it is in the form of steel that its application predominates, in the manufacture of which many other elements are involved, notably carbon, silicon and manganese. But in order to obtain the wide range of properties desired in structural work about twenty-five elements are involved, to a more or less extent, in providing the properties sought. Technical achievements over a long period have built up over 2,000 combinations of this single material, providing a considerable range of types, each designed to serve a specific purpose.

In peace-times Britain imported about 30% of her iron ore and the whole of her manganese, chromium, nickel, tungsten, molybdenum, vanadium and cobalt, elements which are used in the production of steels to produce the wide range of properties required. In view of the emergency conditions, it was necessary to reconsider steel production and to concentrate on those compositions which were most effective and in sympathy with the availability of the materials. The problem was difficult because it involved changes in the existing practice of the manufacturers and users. A very careful study resulted in the sorting out of the steels covered by specifications into 85 categories; these were decided upon the basis of mechanical properties, compositions, or special functions. This result was achieved by the Technical Advisory Committee, constituted by the Special and Alloy Steels Committee, which prepared a schedule of the 85 categories, from which selection was made possible from a relatively few compositions and treatments to facilitate mass production.

Although reference has been made to only one of the many base metals, and to the elements necessary to obtain the required properties in the finished materials, considerable work has been done in making the best use of the tonnages of non-ferrous metals available, and to apply them as effectively as possible according to the incidence of availability. Particular mention may be made of tin which, in normal times, plays so important a part in industry. Since Japan began the Far Eastern campaign the amount of tin available to allied and neutral nations has been seriously curtailed. This has necessitated not only making the best use of the supplies available by curtailing the use of tin in commodities not essential to the war effort, but in modifying tin-containing alloys so that some or even all the tin is substituted by some other element. A notable development in this direction is a tin-free gear bronze by the Hamilton Gear and Machine Co. containing between 1·5 to 2·5% nickel and 7 to 8% antimony. It is claimed that worm gears of this copper-nickel-antimony alloy carry about 25% more load than tin bronze, and will run about 15° F. cooler at the same load.

In the non-ferrous field it is difficult to say which of the main base metals are most important for war purposes. It is probable, however, that copper and its alloys have the most varied applications, and under present conditions it is likely that the greatest single purpose consumption is in the manufacture of cartridge brasses. There can be no doubt, however, that the proportionate increase in demand for aluminium and magnesium has exceeded any other base metal. The great demand for these metals in the aircraft industry has necessitated greatly increased production, and in the United States and Canada, especially, phenomenal strides have been made in this respect. The United States, for instance, planned for an annual magnesium production rate of 265,000 tons by the end of this year. The increasing demand has led to concentration on the development of new processes whereby raw materials that formerly seemed of little or no value have suddenly assumed prime importance.

The largest demand for aluminium at the present time is for aircraft engine and airframe construction, and when it is realised that the approximate amount used in bomber construction averages about 1,000 lb., excluding propellers, and considering the tremendous surge in the construction of warplanes, little imagination is needed to appreciate the great strides made in the production of both primary and secondary aluminium, and in the application of these in the manufacture of alloys to satisfy exacting specifications.

When the full story is told, the achievements in both ferrous and non-ferrous production and the work involved in meeting the various demands for alloys possessing the essential properties for the services required will be recognised as constituting a vital contribution to victory.

A National Policy for Industry

WHILE the Fighting forces are gradually getting a tighter grip on the enemy, and the nation is applying its resources in man-power and materials towards victory, there is a growing demand for post-war planning in order that sound schemes of reconstruction may be put into operation immediately the conflict has been won. From time to time we have endeavoured to stress the need for such planning because of the conviction that the stable part of victory depends not only on military success, but upon a preparedness to meet economic, financial, social and cultural phases of the struggle. Actually, the broader aspects of the conflict which await post-war solution are vitally a part of the war itself, and the increasing attention being given to these aspects must induce hope for the future.

Too many are familiar with the chaos that followed the last war to be in any doubt about the aftermath of the present war, unless precautions are taken. The problems, for which solutions must be sought, are greater and are complex. Industrial problems alone will be difficult of solution. Consider briefly the facts. Millions of people have ceased the production of utility goods and are concentrating on destruction, while within the war zone vast reserves of real wealth in all forms are fast disappearing. Normal production, trade, transport and finance are disrupted as never before. Acute shortages of basic necessities face whole populations in many countries. Yet the productivity of the earth and the productive capacity of mankind will remain. Obviously reconstruction will be a stupendous task, but we believe that the efforts now being made are inspiring a spirit of confidence in the future.

Some light is thrown on this subject of reconstruction by a memorandum published with the support of responsible representatives of British industry. The signatories to this memoradnum regard it as fatal to do nothing about post-war problems, and suggest a national policy for industry. It is not claimed that the views expressed constitute a solution for all the problems with which industry and the community will be faced at the conclusion of hostilities. The proposals made need to be examined, developed and elaborated, but the signatories are justified in maintaining that if industry could be organised on the lines indicated it should be possible not only to achieve greater economic security and a higher standard of life for the community but to ensure that all engaged in industry are made aware of their clear responsibility for conducting industry in accordance with the needs of the community.

As a producer industry is by far the largest contributor to the material welfare of the nation. It has a threefold public responsibility: to the public which consumes its products, to the public which it employs, and to the public which provides the capital by which it operates and develops. The underlying conviction on which the whole of this document is based is that the spirit which should animate industry is service to the community as a whole.

The statement is presented in four sections. The first reviews the achievements of industry, outlines the problems which it will have to face after the war, and indicates the social and other obligations it will have to assume if it is to solve these problems successfully and to discharge its threefold public responsibility. The trend of thought in the preparation of this document is admirably shown by the statement that the responsibility of those directing industry is to hold a just balance between the varying interests of the public as consumers, the staff and workmen as employees, and the stockholders as investors, and to make the highest possible contribution to the well being of the nation as a whole. Continuous improvements in the spirit and organisation of industry were in progress before the war. One of the tasks is to improve upon these improvements and to remove any shortcomings there were in industry's approach to the handling of these questions, industrial, economic and social, with which it is concerned. But a whole range of new and formidable problems will have to be faced after the war, great changes therefore will have to be made in industry. To effect genuine and permanent improvement, however, it is the signatories' conviction that the changes which are to be made must be evolutionary and practical rather than revolutionary and abstract. They must spring from past experience and be based on a true analysis of fact.

The various forms or frameworks within which industry can function are discussed in the second section. The signatories emphasise their belief in the system of private enterprise. They assert that while Government control is necessary and possible in war-time, when the resources of the country are concentrated on a single objective, but unhesitatingly take the view that its extension in times of peace, when industry has to meet an immense variety of changing needs, would be wasteful, clumsy and destructive of development and initiative. The management of industry needs imagination, initiative, and an urge to lead in technical development.

The general lines upon which closer organisation of industry could proceed are discussed in the third section. The main point in this section being that the relations between firms, between different industries and between industry as a whole and Government should be more fully and comprehensively organised in some form of permanent association; otherwise, there will continue to be loss and friction through forms of competition which are wasteful and uneconomic.

An important recommendation is that a Central Council of Industry, representative of the whole industry, be brought into being. Such a Council is needed to formulate the views of industry on questions transcending the limits of any one trade, especially questions on which different sections may take different views. In the transitional period from war to peace there will be particular need for the advice of such a body, and it is certainly advisable that all existing national associations and federations which represent industry should be brought into consultation together as early as possible on the right means of forming it.

The steps taken to bring these proposals nearer to fulfilment are stated in the last section. These include the appointment of a committee to examine, in much closer detail, the general questions discussed in this document, to collaborate with other interested parties, and to confer with the existing national associations and federations. Their ultimate task is to report upon the specific action which is called for.

This document, a copy of which may be obtained from Mr. A. R. Smith, c/o Thomson McLintock and Co., Granite House, 101, Cannon Street, E.C. 4, has involved considerable thought; it provides a very useful basis upon which to build a responsible authority to discharge the responsibilities of industry and maintain the spirit of service to the community as a whole. One important factor which has seriously interfered with industry in the past, and about which no mention is made, is the demoralising uncertainty of certain raw material prices; in the period between the two great wars, for instance, the price of copper fluctuated between £30 and £118 per ton. This, of course, is only one instance of many that could be quoted from official figures, and we believe that Government control is necessary to effect stabilisation in prices of primary materials. The proposals made in this document can be regarded as an outstanding contribution to the solution of post-war problems.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

Some New Developments in Magnesium Alloy Technology

By F. A. Fox, M.Sc.

War conditions have greatly increased the demand for magnesium alloys, especially for use in aircraft production, and while considerable work has been carried out to increase supplies of this strategic material, research work has led to increased knowledge of the treatment and properties of suitable alloys. A brief reference is made to some of these technical developments.

UNDER war conditions the use of magnesium alloys has greatly increased, and it must have been a difficult matter, from the national point of view, to decide exactly how the available magnesium could best be utilised. Not only does the use of magnesium offer considerable technical advantage in the engineering field, but magnesium-base materials have also other military uses which they alone can fulfil.

There has been a very large expansion in the production capacity for magnesium alloys, not only in this country, but also in the United States. While the 1939 production in this country was about 6,000 tons per annum, that in America was only about 3,000 to 3,500 tons per annum. The published production targets for the United States are about 190,000 tons per annum for the end of 1942, and about 350,000 for the end of 1943. This is a production development so rapid as to be almost fantastic, and is an effort to which British methods will have made a valuable contribution.

The compositions of the alloys in use in this country have not changed in very recent times, and those employed in the United States are also generally similar. The properties of the principal casting alloys are shown in Table I.

TABLE I.

COMMERCIAL MAGNESIUM CASTING ALLOYS.

Alloy.		D.T.D. Specification.	Condition.	Average Tensile Properties.			Ultimate Stress Specific Tenacity.	Proof Stress Specific Tenacity.
Elektron Designation.	Nominal Composition, %.			0·1% Proof Stress, Tons/sq. in.	Ultimate Stress, Tons/sq. in.	% Elongation on 2 in.		
AM.503	Mg + 1·5 Mn	140A	Sand-cast	1·9	7·0	7·0	4·0	1·1
AZ63	Mg + 6 Al + 3 Zn	59A	Sand-cast	5·0	12·5	5·0	6·9	2·7
A.8	Mg + 8 Al + 0·4 Zn	59A	Sand-cast	5·3	10·5	3·0	5·8	2·9
AZ.91	Mg + 9·5 Al + 0·4 Zn	136A	Sand-cast	6·0	9·6	1·5	5·3	3·3
A.8	Mg + 8 Al + 0·4 Zn	59A	Die-cast	5·8	14·0	8·0	7·7	3·2
AZ.91	Mg + 9·5 Al + 0·4 Zn	136A	Die-cast	6·0	12·5	3·0	6·9	3·3

All the aluminium-containing Elektron alloys carry 0·15—0·40% manganese.

One slight difference between American alloy practice and that in this country is that a greater usage of the alloy containing 6% aluminium and 3% zinc has continued in America: in this country there has been a tendency to work with a higher aluminium content and a reduced amount of zinc. While the higher zinc contents (1% or over) do seem to confer somewhat slightly improved corrosion resistance, they introduce a widening of the freezing range of the alloy, and, apparently mainly for this reason, the higher zinc alloys tend to be microporous. This microporosity, which seems to be almost entirely the result of loss by shrinkage of interdendritic liquid, may cause loss of pressure tightness where the cavities are interconnected. It is probable that American practice is, in recent times, beginning to favour an increase in the aluminium content and a decrease in the zinc content because of this difficulty.

It is interesting to compare the mechanical properties of Table I for "as-cast" magnesium alloys with those obtained in as-cast aluminium alloys. Some of these properties for aluminium alloys are given in Table II. It will be seen that the specific tenacity figures, whether based on ultimate strength or on proof stress, are favourable to magnesium alloys.

TABLE II.

NON-HEAT-TREATED ALUMINIUM CASTING ALLOYS.

Alloy.	Nominal Composition. %.	Specification.	Condition.	Average Tensile Properties.			Ultimate Stress Specific Tenacity.	Proof Stress Specific Tenacity.
				0·1% Proof Stress, Tons/sq. in.	Ultimate Stress, Tons/sq. in.	% Elongation on 2 in.		
Alpax	Al + 13 Si (mod.)	B.S.S. L.33	Sand-cast	5·0	10·5–11·5	5–7	4·3	1·9
	Al + 5 Si	A.S.T.M. B26—36T Alloy J or JJ	Sand-cast	3·5	7·5–8·5	3–6	3·2	1·3
Cupralumin	Al + 8 Cu	B.S.S. 4 L11	Sand-cast	4·0	8·0	2·0	2·8	1·4
	Al + 7 Cu + 1·2 Fe + 2 Si + 1·5 Zn	A.S.T.M. B26—37T Alloy C	Sand-cast	4·5	9·0–10·5	1·5	3·6	1·6
	Al + 7 Cu + 2 Si	A.S.T.M. B85—37T Alloy XII	Die-cast	7·0	12·0	2·0	4·2	2·5

TABLE III.

THE EFFECT OF HEAT-TREATMENT ON THE MECHANICAL PROPERTIES OF THE ELEKTRON ALLOYS A.8 AND AZ.91.

Elektron Alloy.	Nominal Composition, %.	D.T.D. Specification.	Condition.	Average Tensile Properties.		
				0·1% Proof Stress, Tons/sq. in.	Ultimate Stress, Tons/sq. in.	% Elongation on 2 in.
A.8	Mg + 8 Al + 0·4 Zn	59A	As cast	5·3	10·5	3·0
A.8	Mg + 8 Al + 0·4 Zn	289	Solution treated	5·1	17·0	12·5
AZ.91	Mg + 9·5 Al + 0·4 Zn	136A	As cast	6·0	9·6	1·5
AZ.91	Mg + 9·5 Al + 0·4 Zn	281	Solution treated	6·0	17·0	9·0
AZ.91	Mg + 9·5 Al + 0·4 Zn	285	Solution treated and aged	7·5	17·0	1·5

All the above Elektron alloys carry 0·15—0·40% manganese.

Heat-Treatment

In Table III are given the properties of the magnesium casting alloys in heat-treated condition. This method of enhancing the properties is widely used, and a large proportion of the magnesium alloy castings used in aircraft are in the heat-treated condition. An alloy conforming to D.T.D. specification 59A, and containing about 8% aluminium, 0·4% zinc and 0·3% manganese (Elektron A.8), is given a 24-hour solution treatment time, the solution treatment temperature being about 410° C. The supersaturated solid solution thus produced is relatively stable, and no spontaneous room-temperature ageing phenomena

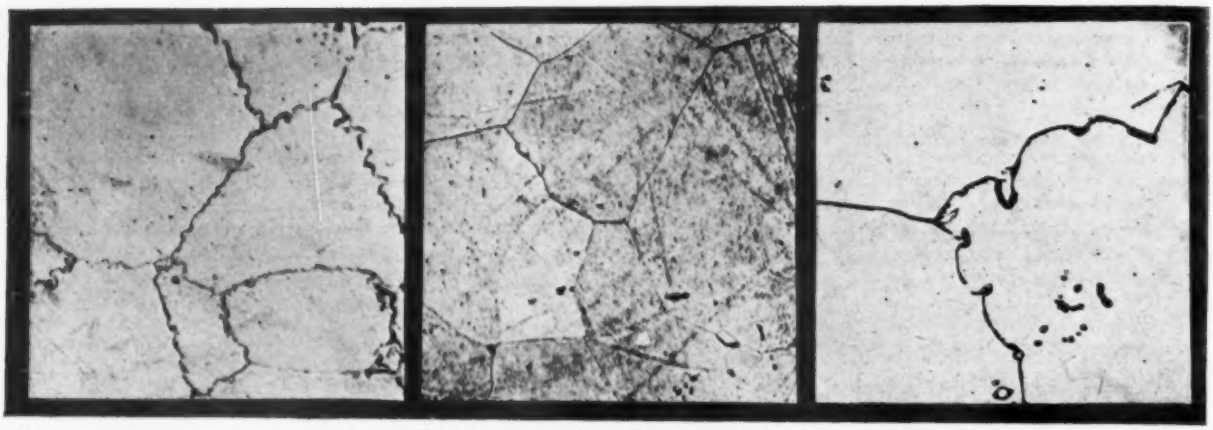


Fig. 1.—Magnesium alloy containing 8% aluminium, solution-treated and air-cooled, showing crinkled grain boundaries. x 600.

Fig. 2.—Magnesium alloy containing 8% alluminium, solution-treated and water-quenched, showing polygonal grain boundaries. x 600.

Fig. 3.—Magnesium alloy containing 8% aluminium, solution-treated and air-cooled, showing precipitated beta-phase in grain boundary. x 1,000.

have been observed. The rate of precipitation of the beta-phase is such that the alloy does not need to be quenched from the solution treatment temperature and can be air-cooled.

Recent work in the laboratories of Magnesium Elektron Limited[1] has shown that there is a slight microstructural difference between air-cooled and quenched-solution treated specimens, and a peculiarity of the microstructure of air-cooled solution treated specimens has been explained. This peculiarity is that the grain boundaries of the apparently homogeneous solid solution tend to be crinkled. If, however, the alloy is quenched from the solution treatment temperature, or from temperatures above about 390° C., the structure is slightly modified in that the grain boundaries are no longer crinkled and the structure is characteristic of that of a homogeneous polygonal grained solution. If the crinkled grain boundaries are examined at higher magnification it is found that the indentations are associated with local grain boundary beta-phase precipitation. Figs. 1, 2 and 3 illustrate these points. The beta-phase precipitation causing the crinkling of the grain boundaries is different from the usual "pearlitic" type of precipitate, which is produced in large field areas of the solution-treated material when low-temperature precipitation is applied. Here the precipitated material is in finely divided form and closely intermingled with alpha-solid solution. It may take a variety of forms, although in ordinary precipitation-treated alloys for general use, it is of the "pearlitic" or "troostitic" type (Figs. 4 and 5).

1 A. Fisher. *Journal of the Institute of Metals*, vol. 67, part 9, 1941.

The grain-size of castings for heat-treatment may have much effect on the perfection of solution treatment produced by a given thermal treatment, the larger the grain-size the coarser will the particles of beta-phase be, and the more difficult will it be to take them into solution. This difficulty may increase sharply with increasing grain-size, and it is therefore necessary to ensure by every means possible that the grain-size of a casting for heat-treatment is as uniform as possible at all points. Imperfect solution will, of course, not only affect the degree of solution treatment, but also the amount of precipitate formed on subsequent precipitation treatment. Correct superheating of the alloy before casting and proper attention to the conditions of chill in the mould remain the principal methods of controlling the grain-size of castings.

Wrought Alloys

The compositions and mechanical properties of the wrought alloys are given in Table IV.

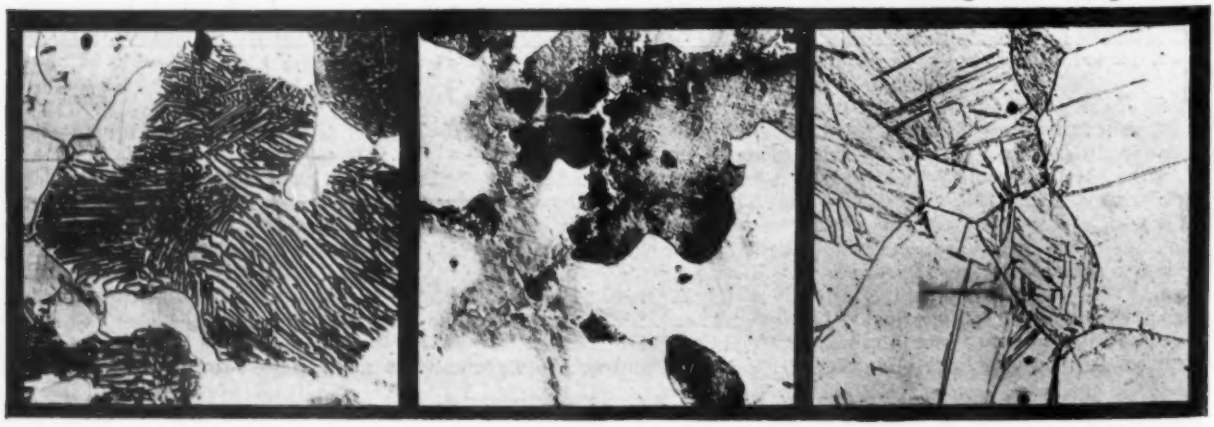
The principal wrought alloys used are the alloy containing 6% aluminium, 1% zinc, 0·3% manganese (Elektron AZM) in the form of extrusions and forgings, and the rolling alloy containing about 1·5% manganese (Elektron AM.503) in sheet form. The latter alloy, which has outstandingly good corrosion resistance properties, and which is readily weldable, is being used in large quantities for many aircraft components and, *inter alia*, the production of welded tanks for petrol and for other liquid containers for aircraft.

The problem of directionality of sheet in this alloy is

Fig. 4.—Magnesium alloy containing 8% aluminium, precipitation heat-treated, showing "pearlite." x 450.

Fig. 5.—Magnesium alloy containing 8% aluminium, precipitation heat-treated, showing "troostite." x 150.

Fig. 6.—Magnesium alloy containing 1.5% manganese, showing secondary manganese particles precipitated from matrix outlining strain workings. x 120.



of little practical importance, since it amounts only to differences of the order of 1 ton/sq. in. in the ultimate tensile strength. Furthermore, the sheet is fabricated hot in the temperature range, 300° to 400° C., where directionality effects are greatly reduced or eliminated.

TABLE IV.

COMMERCIAL MAGNESIUM WROUGHT IRONS.

Alloy.		D.T.D. Specification.	Condition.	Average Tensile Properties.			Ultimate Stress Specific Tenacity.	Proof Stress Specific Tenacity.
Elektron Designation.	Nominal Composition, %.			0·1% Proof Stress, Tons/sq. in.	Ultimate Stress, Tons/sq. in.	% Elongation on 2 in.		
AM.503	Mg + 1·5 Mn	142	Extruded	10·0	18·0	3·0	10·1	5·6
AM.503	Mg + 1·5 Mn	118	Sheet	8·0	15·0	7·0	8·4	4·5
AZM	Mg + 6 Al + 1 Zn	259	Extruded	15·0	20·0	12·0	11·0	8·3
AZM	Mg + 6 Al + 1 Zn	88B	Forging	8·0	15·0	5·0	8·3	4·4
AZM	Mg + 6 Al + 1 Zn	348	Tube	9·5	16·0	7·5	8·9	5·3
AZ.855	Mg + 8 Al + 0·4 Zn	88D	Forging	15·0	22·0	12·0	12·1	8·3

All the aluminium-containing Elektron alloys carry 0·15—0·40% manganese.

The directionality in this magnesium alloy sheet is, however, of interest from a theoretical point of view, since it is such that the properties in the transverse direction tend to be better than those in the longitudinal direction. This alloy consists essentially of a solid solution of manganese in magnesium, although there may be some second phase present consisting either of primary manganese particles or of very much smaller manganese particles precipitated from the solid solution under the influence of mechanical work and elevated temperatures. This latter type of precipitation is shown in Fig. 6, outlining strain markings.

A paper by P. W. Bakarian[2] describes the results of some work carried out in America in which it is stated that the rolling texture of magnesium sheet, and of rolled magnesium alloy sheet (of the magnesium-manganese type), is modified by the presence of about 0·15% calcium; this is said to produce a double orientation with two predominating angles of intense basal plane concentration. This double orientation is thought to be due to a combination of twinning and glide with further slip of twinned material. The presence of the calcium has been thought to influence the choice of operating slip planes, and that this has influenced the rolling texture produced.

The state of knowledge concerning orientation, slip and twinning in magnesium alloys is not far advanced, and these questions will no doubt be the subject of further investigation.

2 Metals Technology, August, 1941, paper No. T.P. 1355.

Corrosion

The methods of working and the methods of protecting magnesium alloys have some time ago reached such a satisfactory state that the corrosion of magnesium alloys is not a serious problem. The alloys in the protected state will remain unchanged indefinitely under exposure to ordinary atmospheres, and the resistance to salt-laden atmospheres is also good. Research work directed to improve still further the corrosion resistance is continuing from the point of view of improvement in protective schemes, and also from the point of view of compiling the most precise data concerning the effects of the constituents and the impurities in the alloys. It has long been known that small quantities of iron are harmful to magnesium alloys from the corrosion point of view, and papers have been published in America dealing with the effect of this and of other elements.

A paper by Hanawalt, Nelson and Peloubet[3] discussed the effects of nickel and copper as well as of iron and showed that all three elements are dangerous, although the adverse effects of nickel and iron can be neutralised to some extent by the presence of the manganese, which has been added to all magnesium alloys for many years.

The harmful effect of small amounts of copper in the aluminium and zinc containing alloys is not great, and it is stated that up to 0·5% could be tolerated.

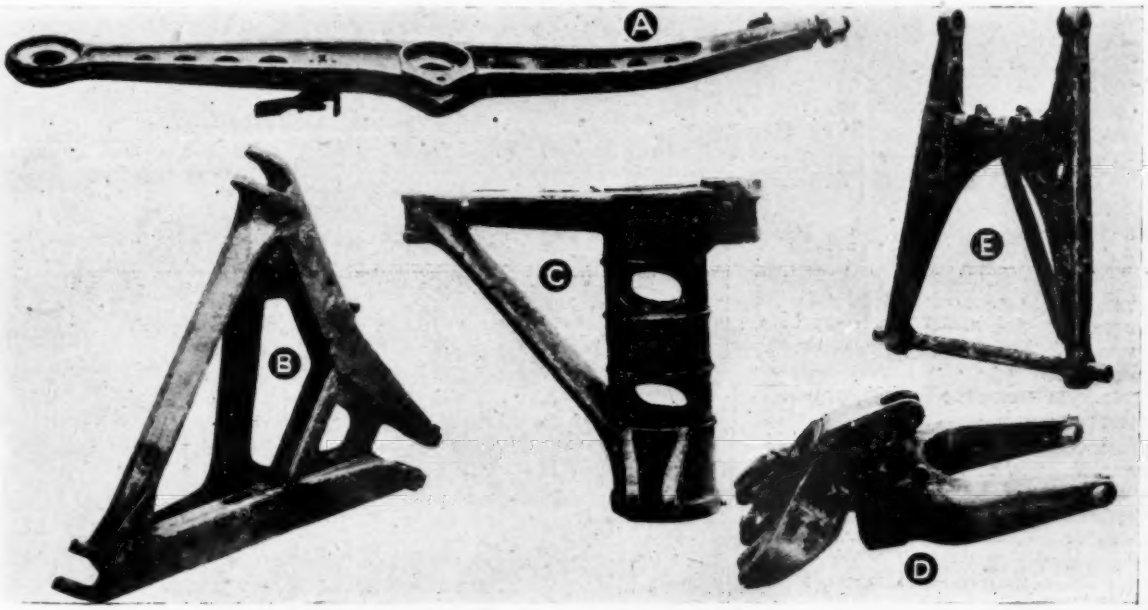
The likelihood of the presence of nickel in properly produced magnesium alloy ingot is negligible, since it can be introduced only from the use of nickel-containing secondary aluminium ingot in the alloying stages.

A later American patent[4] states that it is desirable not to eliminate the nickel entirely but to ensure the presence of a positive amount of nickel not exceeding 0·001%. It

3 Metals Technology, VIII, Sept., 1941, No. 6, A.I.M.M.E., Technical publication No. 1353, 26 pp.

4 U.S. Patent No. 2,264,308.

Fig. 8.—(A) JU 87 engine bearer. (B) Dornier 217 under-carriage leg mounting. (C) Undercarriage mounting bracket. (D) Heinkel HE 111 undercarriage radius arm. (E) Tailw-heel fork and bracket.



is claimed that while this is below the limit for adverse corrosion effects, its presence is necessary to improve the working characteristics; the nature of this improvement is, however, not specified.

According to some Japanese workers,[5] the additions to the well-known corrosion-resistant alloys of the magnesium-manganese type can be made to improve the corrosion resistance still further. These additions were said to be calcium, mercury, arsenic, tellurium and selenium. The practicability of some of these additions seems, however, to be very doubtful.

A German paper by Fahrenhorst and Bullien[6] has given some interesting data on the occurrence of iron in pure magnesium and in magnesium-manganese alloys. According to this work the solubility of iron in magnesium at the melting point is only 0·026%, but it increases to 0·84% at temperatures near the boiling point. With magnesium-manganese alloys containing up to 1% manganese practically similar results were said to have been obtained. The 2% manganese alloy, however, is said to dissolve much less iron at temperatures below 900° C., although the rate of solution of iron above this temperature again increases. At the melting point of magnesium, 2% of manganese is said to reduce the iron solubility from 0·026% to 0·006%.

It is probable that an important factor is the manganese-iron ratio, which should exceed a certain figure if good corrosion-resistant properties are to be obtained.

Inspection

The inspection of magnesium alloys falls generally into three categories—by fracture, by X-ray examination, and by mechanical testing. The fracture test is still widely used as an indication of the grain-size of the alloy, and it is also an index to the presence of microporosity. Where microporosity is present a yellow stain may be observed, which in a heat-treated alloy may appear as a brown discoloration.

The use of X-ray examination in the non-destructive testing of magnesium alloy parts has increased with the increase in production, and possibly also as the state of knowledge on its application to these alloys has advanced. With a properly taken radiograph it is possible to observe not only macro cavities and defects but also microporosity. The latter appears as cloudy markings on the radiograph, and under favourable conditions can be detected in sections up to about 1 in. thick. Radiographic conditions tending to produce as high a definition as possible should be used.

It is an interesting and not easily explicable fact that the grain-size of even thick magnesium alloy pieces is shown up on the radiographic film; in general, the slight mottling effect associated with this grain-size phenomenon does not cause any difficulty in the interpretation of radiographs. An interesting extreme case is illustrated in Fig. 7. This is a radiograph of a slice of an experimental magnesium billet with coarse columnar grains. The section was 1 cm. in thickness, and the radiograph matches the macrostructure, as revealed by ordinary methods, so perfectly that one can hardly tell the difference between the radiograph and a photomacrograph.

While gross defects can be seen in magnesium-alloy castings by using screening methods, the radiographic technique is preferable for a close inspection.

Work in the laboratories of Magnesium Elektron Limited has indicated that the surface finish of magnesium-alloy test bars is not so critical as might be supposed when casting alloys are being tested. The difference between average properties from bars to D.T.D. 136A as turned, ground and polished, and between bars tested as turned, is in fact negligible, even as far as elongation values are concerned.

The mechanical properties of cast-to-shape test bars have also recently been compared with those obtained from the conventional D.T.D.-type test bar.[7] This has shown that even the as-cast surface appears to introduce only minor variations in strength properties. In the case of fully heat-treated alloys, e.g., D.T.D. 285, the use of cast-to-shape test bars does result in low elongation figures. In the case of wrought magnesium alloys, the influence of finish on test-bar properties is much more marked.

Applications

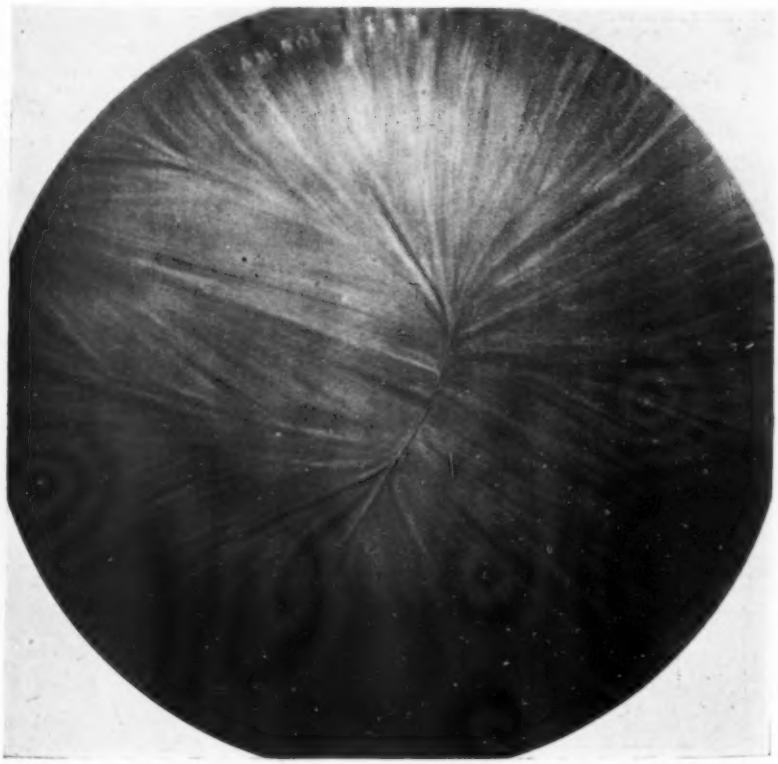
The engineering applications of magnesium alloys are under present conditions exclusively confined to aircraft uses. The main use is in the form of castings for such purposes as landing wheels, control levers and engine castings. Large undercarriage parts are also made in magnesium alloy and sand castings weighing over 2 cwt., each are now being made for such purposes. In addition to magnesium alloy petrol tanks, the sheet is also used in control surface construction on certain machines. A considerable quantity of extruded tube is used in the manufacture of welded pilot's seat construction.

Much German nagnesium alloy has found its way into British melting pots in the form of parts of crashed German aircraft. The usage of magnesium on these machines is rather larger than in this country, and the accompanying photographs show magnesium alloy components taken from German aircraft wreckage (Fig. 8).

7 *Magnesium Review and Abstracts*, vol. III, No. 1.

Fig. 7.—Radiograph of a slice of an experimental magnesium alloy billet with coarse columnar grains. 50 kv. 10 milliamps. 10 mins. exposure. 5 ft. from tube. Crystallex film.

Reduced on reproduction to half size, linear measurement.



5 Obinata and Hayashi, *Nippon Kinzoku Gakkai-Si*, 1940 (May), vol. 4, No. 5, p. 146.

6 *Z. Metallkunde*, 1941 (January), vol. 133, p. 31. The data presented in the text have been taken from an abstract (as given in British Chemical Abstracts) and not from the original paper.

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

THIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. In this, the fifth of the series, is presented a summary of the results of investigations on camshafts and airscrew shafts and on various castings forming parts of landing or take-off gear and parts of the fuselage.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

Section X.—Camshafts and Airscrew Shafts

A.—CAMSHAFTS

ONLY two camshafts were examined. One of these consisted of a portion from a Junkers Jumo 211A engine (Heinkel 111H) (Report No. 7), whilst the other was a complete shaft from a Mercedes-Benz DB. 601A engine (Report No. 20). Both had been case-carburised on the bearing surfaces. Their analyses and mechanical properties are given in Tables I and II respectively.

The Jumo 211A camshaft included five groups of cams, each consisting of two inlet and one exhaust, while those of the DB. 601A shaft were arranged in pairs, the individual cams of each pair being in line, indicating that they probably operated both inlet and exhaust valves. There were six such pairs in all. Figs. 1 to 3 illustrate these and other features.

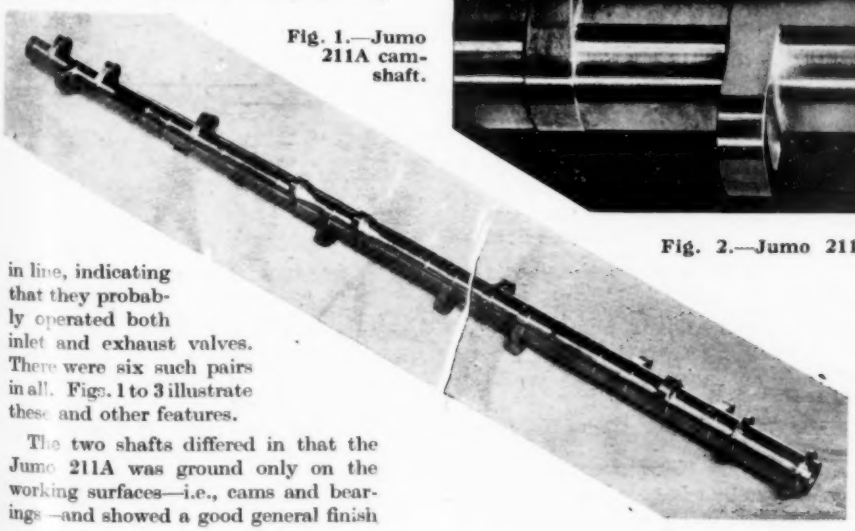


Fig. 1.—Jumo 211A camshaft.

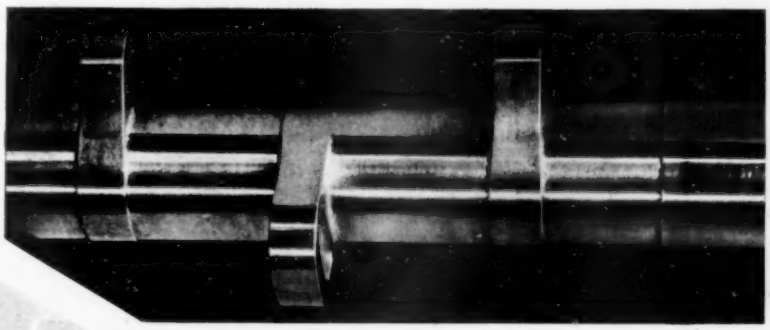


Fig. 2.—Jumo 211A camshaft (part enlarged).

The two shafts differed in that the Jumo 211A was ground only on the working surfaces—i.e., cams and bearings—and showed a good general finish in these positions. The Mercedes-Benz DB. 601A, on the other hand, was well finished all over. In both cases there was evidence of slight scoring.

Composition

Two different types of steel were found to have been employed—viz., the Jumo 211A shaft consisted of a 1¾% chromium, 1·5% nickel, 0·22% molybdenum steel of the case-hardening type, whilst the Mercedes-Benz DB. 601A shaft was of a 1% chromium-molybdenum steel containing 1% manganese. The sulphur and phosphorus contents of both steels were very low. (See Table I.)

Method of Manufacture

Both shafts were probably made from electric arc steel.

The method of preparation before the actual carburising differed somewhat, the procedures probably being as follows:—

Jumo 211A—Drop-forged, rough-machined, leaving excess material where the shaft was ultimately required to be soft, and then carburised. The part was then finished machined, the case being removed where the shaft was ultimately required in the soft condition.

TABLE I.
CAMSHAFTS AND AIRSCREW SHAFTS: CHEMICAL COMPOSITION.

Report No.	Type of Engine.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	Cu.	Al.	Ti.
7	Jumo 211A	Camshaft	0·13	0·22	0·38	0·008	0·010	1·59	1·75	0·22	—	—	—
20	Mercedes-Benz D.B. 601 A	Camshaft	0·23	0·38	0·94	0·010	0·012	0·32	1·07	0·22	0·06	0·06	trace
36	Bramo Fafnir 323P	Airscrew Shaft	0·34	0·23	0·40	0·009	0·016	1·83	2·06	0·41	0·09	0·11	—
83	Fiat A. 80 RC.41	Airscrew Shaft	0·29	0·24	0·70	0·008	0·010	2·98	1·08	0·51	—	—	trace

craft materials, although occasional long silicate stringers were observed in the Jumo 211A shaft.

Hardness

Both camshafts were found to be carburised, and while one composition (Jumo 211A) was obviously a case-hardening type, the other shaft (DB. 601A) was rather an unusual type for this purpose. Being substantially nickel-free, however, the comparatively high carbon content of this latter material had no doubt been used with the idea of obtaining a satisfactorily high hardness on the uncased parts and as a substitute for nickel which is normally present with chromium in case-hardening steels of high core strength.

Fig. 3.—Mercedes-Benz D.B. 601A camshaft.

Fig. 6.—Normal case on bearing of Jumo 211A camshaft. x 40.

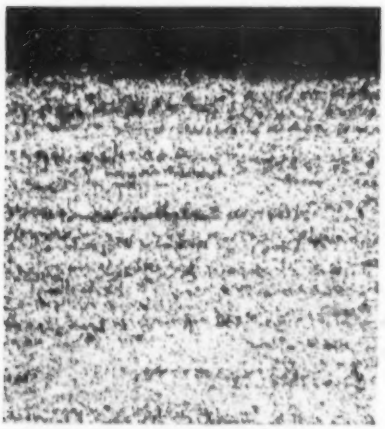
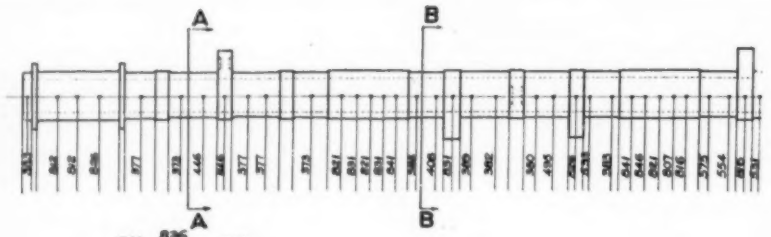
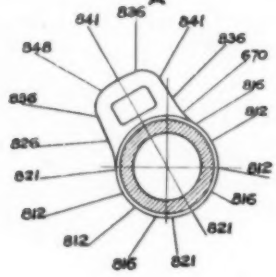


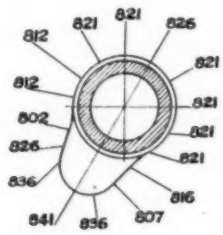
Fig. 7.—Core structure of bearing of Jumo 211A crankshaft. x 40

It was then finally heat-treated and finished ground.

DB. 601A.—Machined from bar stock to size, plus a grinding allowance on the wearing parts only, and then carburised. The parts not required to be hard were protected against carborising in some manner, but this appeared to have been ineffectively carried out as a patchy remnant case was observed on these parts. The shaft was then finally heat-treated.



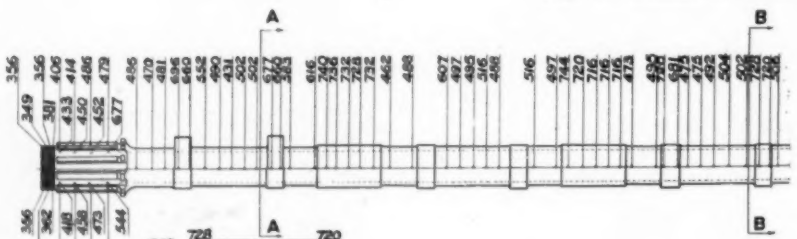


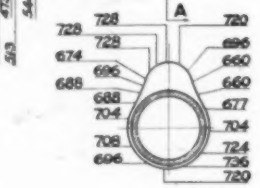


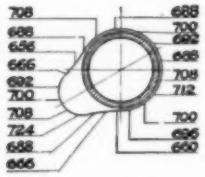
ENLARGED SECTION A-A

ENLARGED SECTION B-B

Fig. 4.—Details of Jumo







ENLARGED SECTION A-A.

ENLARGED SECTION B-B.

Fig. 5.—Details of Mercedes-Benz

Grain Size

The Jumo 211A shaft was found to have an inherent coarse grain size (Index No. 1–2), and the DB. 601A shaft was medium to fine (Index No. 4 to 6).

Cleanness

Generally speaking, both steels compared reasonably well with British air-

The hardness and tensile data may be summarised as in Table II.

The general hardness of the wearing surfaces of the DB. 601A shaft is lower than usual for this class of part, and the erratic hardnesses found on these parts is considered to be due to insufficient quenching. Some variations on the case hardness of the several cams from the Jumo engine were later found to be due to variation in case depth. For fuller details see Figs. 4 and 5 and Table II.

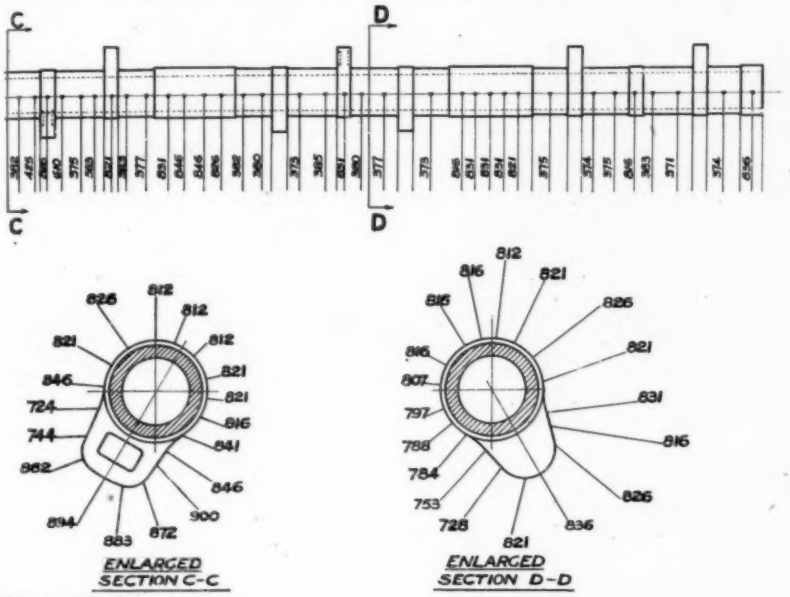
TABLE II.
CAMSHAFTS AND AIRSCREW SHAFTS: HARDNESS VALUES AND MECHANICAL PROPERTIES.

Report No.	Type of Engine.	Component.	Grain Size.	Diamond Hardness.		Y.P. Tons/sq. in.	M.S. Tons/sq. in.	El., %.	R.A., %.	Izod Ft.-lb.
				Case.	Core.					
7	Jumo 211A	Camshaft	1 to 2	846 max.	373—390	—	—	—	—	—*
20	Mercedes-Benz D.B. 601	Camshaft	4 to 6	779 max.	450	—	—	—	—	—
36	Bramo Fafnir 323P.	Airscrew Shaft	1 to 3	—	368—383	70·1	75·8	23·0	59·6	58, 59, 64
83	Fiat A. 80 RC.41	Airscrew Shaft	5 to 6	—	340- 332 BHN	72·4	77·2	19·0	60·4	47, 49, 54

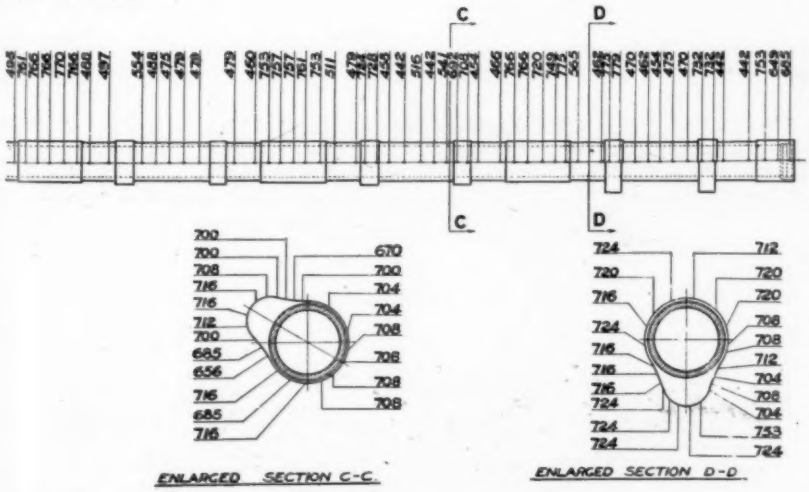
* Bearing surface case-carburised.

Micro-Examination

Both structures indicated that the shafts had been refined after carburising, and free carbide was present in the Jumo 211A shaft, but absent in the DB. 601A. Figs. 6 to 10 illustrate the case and core structures of each.



211A camshaft.



D.B. 601A camshaft.

B.—AIRSCREW SHAFTS

Two only have been submitted to examination, one being from a Bramo Fafnir 323P engine (Report No. 36), and the other from the Italian Fiat A80–RC41 type (Report No. 83). A summary of the essential data is given in Tables I and II.

Both appeared to be well finished, and the general appearance is illustrated in Figs. 11, 12 ,15, and 16. The Italian shaft showed some irregularity in the splining towards the larger diameter end.

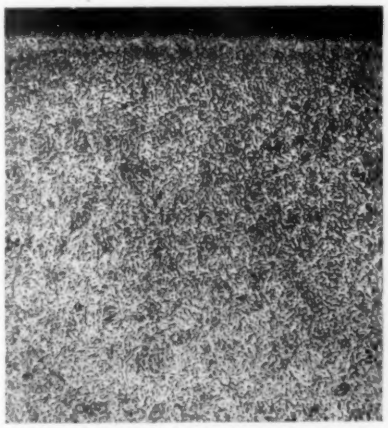


Fig. 8.—Normal case on inlet cam of Jumo 211A camshaft. x 125.

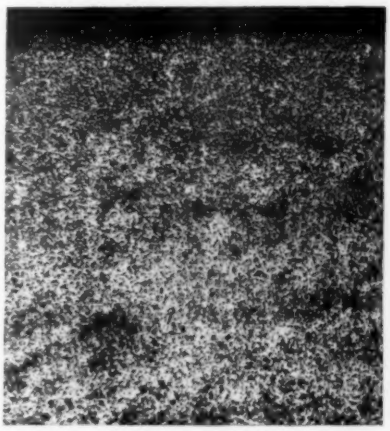


Fig. 9.—Case structure of Mercedes-Benz D.B. 601A camshaft. x 300.

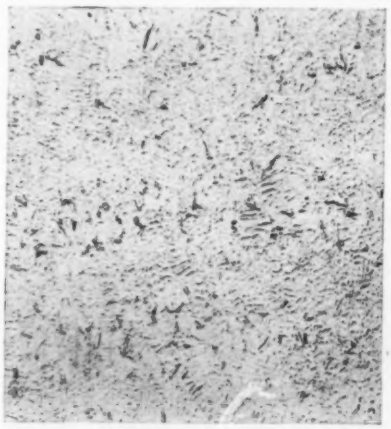


Fig. 10.—Core structure of Mercedes-Benz D.B. 601A camshaft. x 300,

Fig. 11.—Bramo Fafnir 323P airscrew shaft.

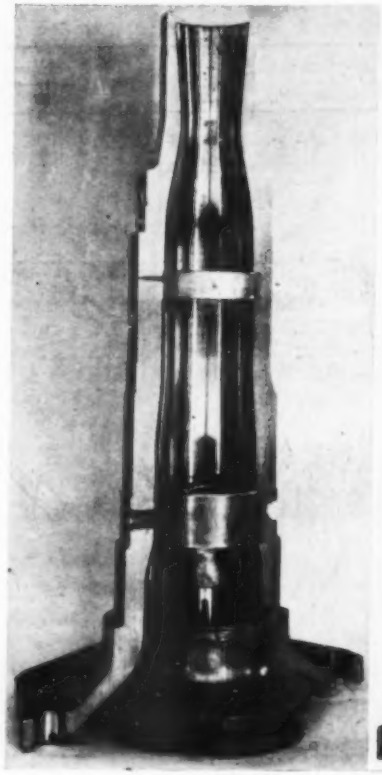


Fig. 12.—Section of Bramo Fafnir 323P airscrew shaft.

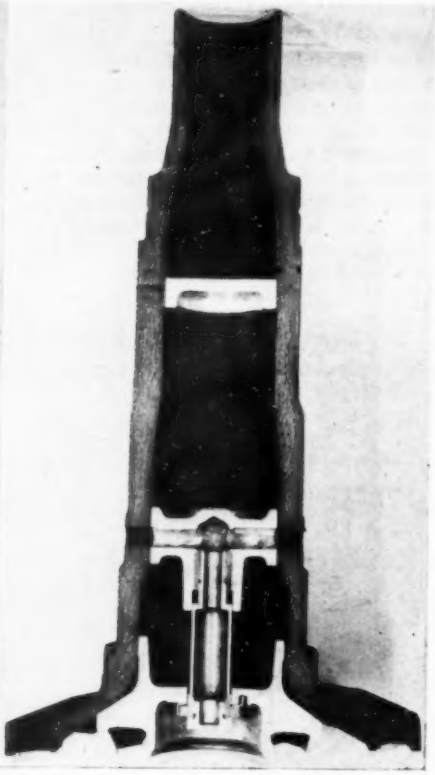


Fig. 13.—Further section of Bramo Fafnir 323P airscrew shaft.

Composition and Method of Manufacture

Both steels were of the nickel-chromium-molybdenum class, but differed in composition as follows:—

(*a*) Bramo Fafnir 323P.—2/2 Ni, Cr, with 0·5% Mo.

(*b*) Italian Fiat A80.RC41.—3/1 Ni, Cr, with 0·5% Mo.

Sulphur and phosphorus contents were very low in both materials, suggesting basic arc steel manufacture. The Italian steel had evidently been titanium treated.

The methods of manufacture of the shafts were different in that the German one appeared to have been made from a tapered forged solid blank by piercing and flanging the wider end, the remainder of the centre being removed by machining. On the other hand, the Fiat shaft was considered to have been made from the solid, reduced by slight forging at the various smaller diameters. Figs. 13 and 17 illustrate these features.

Inherent Grain Size

While the Italian airscrew shaft was found to have a fairly fine inherent grain size (5 to 6), its German companion was rather coarse (1 to 3).

Hardness and Mechanical Properties

Both shafts gave uniform and fairly similar hardness values of approximately 375 V.P.N. and 336 BHN for the German and Italian types respec-

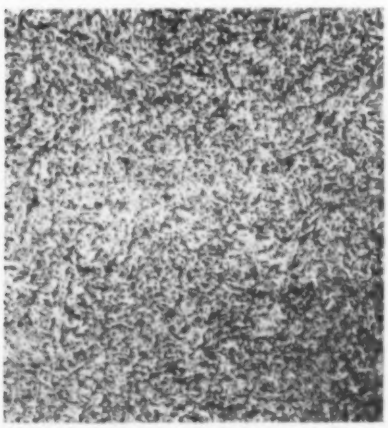


Fig. 14.—Structure of Bramo Fafnir 323P airscrew shaft. x 400.

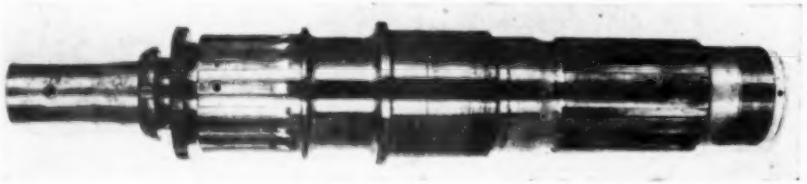


Fig. 15.—Fiat A. 80R.C.41 airscrew shaft.

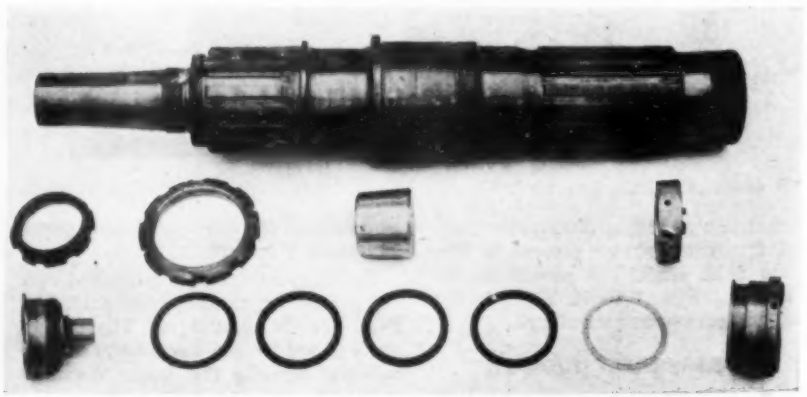


Fig. 16.—Details of Fiat A. 80R.C.41 airscrew shaft.

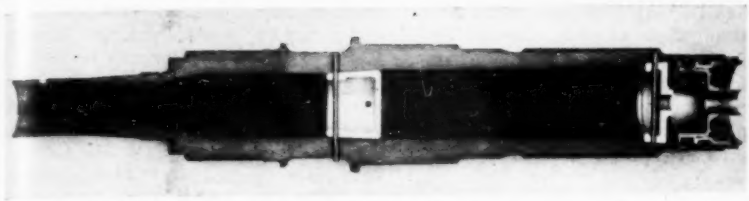


Fig. 17.—Section of Fiat A. 80R.C.41 airscrew shaft.

tively. The tensile strengths were likewise similar, both being in the region of 75–77 tons per sq. in. See Table II.

Micro-Structure

In each case, the etched structure was found to be fine sorbite, suggesting uniform heat-treatment by hardening and tempering. Figs. 14 and 18 illustrate these structures.

Cleanness

Both compared reasonably well with British aircraft steel.

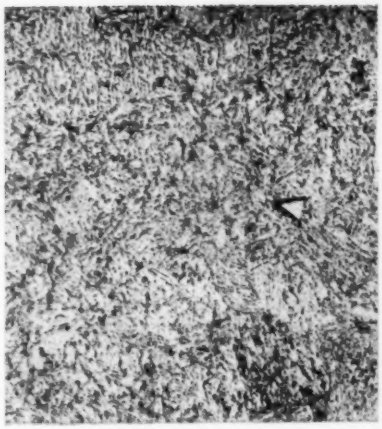


Fig. 18.— Structure of Fiat A. 80R.C.41 airscrew shaft. x 500.

Section XI.—Castings

A NUMBER of German aircraft components were found to have been made as alloy steel castings, and in view of the high quality of these, the sections of the reports dealing with castings were abstracted and issued as a separate report by the Aero Components Sub-Committee of the Technical Advisory Committee. The salient features of the results of the examination are here summarised :—

Of the eight castings examined, five formed parts of the landing or take-off

TABLE I.—COMPONENTS EXAMINED.

Aircraft.	Nature of Component.	Report No.	Reference.
Junkers 88	Shock absorber strut	26	Section XIII D*
Heinkel 111	Assisted take-off hook	34	,, IV†
Heinkel 111 H6	Portion of wing root joint fitting	112	,, XIII C*
Messerschmitt 110	Main undercarriage strut, comprising axle, knee-piece and retraction bracket	49	,, XIII D*
,,	Corner bracket	51	—
,,	V connecting piece from centre-section spar	53	,, XIII B*
Messerschmitt 109	Undercarriage strut, comprising head, torsion link and foot.	65	,, XIII B*
,,	Undercarriage bracket	66	,, XIII B*

* To be published later. † September, 1942, issue.

TABLE II.—RESULTS OF EXAMINATION OF CAST STEEL COMPONENTS FROM GERMAN AEROPLANES (*Continued on page 8*)

Report	Component.	Aircraft.	Description of Component.	Soundness.
26	UNDERCARRIAGE PARTS Shock absorber strut	Junkers 88	The connecting piece and strut are integrally cast. Machined on tubular portion and on mating surfaces of connecting piece. The inside of the strut is machined, whilst the interior of the connecting piece has not been machined, but only shot-blasted	Magnetic testing and X-ray examination revealed no unsoundness, but a section through the lugged flange and head of the central internal supporting fin shows slight unsoundness at the centre. Sulphur printing shows slight segregation only in the vicinity of the unsoundness
34	ASSISTED TAKE-OFF HOOK	Heinkel 111	Roughly a triangular-shaped web flanged round the edges and stiffened by box webbing hook portion at one side of apex. In certain portions the thickness is $\frac{1}{4}$ in. in the as cast thickness. Machined on mating faces—one flange is built up by welding	Microscopic examination reveals a few blowholes
112	PORTION OF WING ROOT FITTING	Heinkel 111—H6	A T-shaped casting with two closely adjacent vertical portions forming the leg of the T. One end tubular	Apparently sound
49	MAIN UNDERCARRIAGE STRUT Axle and knee piece	Messerschmitt 110	Consists of an L-shaped casting with the leg of the L tubular in form. This constitutes the axle portion. The body of the knee-piece was ground except for mating surfaces, which were machined. In the case of the axle the exterior was finely ground and chromium-plated, the interior being rough-bored	Number of small holes visible on chromium plated outer surface
	Retraction bracket		Broadly speaking, consists of a lozenge-shaped casting with an integral rectangular-shaped base, having a fin projecting from upper face. The outer surface was rough, whilst the lugs and interior were machined	Apparently sound
51	CORNER CASTING	Messerschmitt 110	This is a constituent part of a tail plane attachment, and had been machined on fitting faces The thickness of this casting is generally approximately $\frac{1}{4}$ in.	Apparently sound
53	V CONNECTION PIECE FROM CENTRE SECTION SPAR	Messerschmitt 110	V-shaped tubular construction. The arms of the V being machined to tubular shape, while the base of the V was unmachined	Microscopic examination revealed slight porosity
65	UNDERCARRIAGE SUPPORT Head	Messerschmitt 109	There are three constituent parts of this assembly which are castings. The head consists of a cap with an extension piece of roughly triangular form. This has been grit-blasted except on mating surfaces. The cored inside holes have not been cleared of sand. There is some cold lapping on the inside of the casting	Sound and free from segregation There is a small welded area This operation has been carried out prior to to heat-treatment
	Foot		This is an L-shaped tube, the straight portions of the bore having been rough machined before final heat-treatment. Screwed at each end of casting	No unsoundness disclosed
	Torsion Links : Upper Lower		Roughly triangular, with flanged edges. There are lugs at each angle, except that in the case of the upper link the lug at the apex was double	No comments
66	UNDERCARRIAGE BRACKET (Port)	Messerschmitt 109	Three lugs in the form of a triangle with a boss or mass at each angle and various projecting fins. Machined on mating surfaces, remainder ground where accessible	No internal defects. Two fine surface cracks

gear, the other three being parts of the fuselage. The individual components are enumerated, together with the appropriate references, in Table I.

Surface Appearance

All the castings had a good finish, although on many of them a considerable amount of machining had been carried out, not only on mating surfaces, but also on the more highly stressed portions. The component which had the least satisfactory surface was the take-off hook (Report 34), and, as will be observed, the quality of this particular article was, from all aspects, of a lower standard than those items associated with the landing gear. Instances of surface inclusions of sand, general roughness and surface cracks were present in the hook, whereas in the other components such defects were absent, except to the extent that some evidence of roughness and adherent sand was found in those portions which, due to the shape of the castings, were not accessible for machining and/or grinding operations.

Soundness, Etc.

An outstanding characteristic of all the castings examined was their internal soundness and freedom from contraction defects. Only two instances were noted of very slight unsoundness—viz., the shock absorber strut (Report 26) and the V connecting piece (Report 53). Whilst there is no doubt that intensive study of the form of the components had been made in order to evolve a design in which irregular and unsuitable sections were absent, there were instances of relatively speaking large masses inter-connected by smaller sections.

The only important internal discontinuities noted were those associated with non-metallic inclusions. Where these were observed, the castings were sectioned for macro-examination in the position most likely to reveal unsoundness, if such existed. Whilst on many of the castings machining operations have been performed, thereby removing the original cast surface, there were a number of surfaces which exhibited the original condition. These latter, even in the thin sections, showed a good outline, indicating satisfactory running of the steel.

Segregation

No pronounced sulphide segregation was found, except in the few instances where this occurred locally, and in such cases it was associated with unsoundness.

Composition

The composition of the steel was similar in all the examples examined—viz., 1% chromium with 0·25% molybdenum, although one example (Report 53) gave a molybdenum value of 0·40%. Generally speaking, the steels were found to be very pure, as judged from the standpoint of the sulphur and phosphorus content. The analysis results are set out in detail in Table III, and attention is drawn to the relatively high phosphorus content of the take-off hook, as compared with the other castings.

Accidentally introduced elements in the form of nickel and copper were not present to any great extent; in fact, in certain instances the nickel content was so low as to suggest either scrap specially selected from the point of view of freedom from admixture or that the charge contained a high proportion of specially pure iron.

Only in two instances had vanadium been detected, and the proportion suggested that it might have been accidentally introduced in the raw material. Where aluminium had been determined it was not present in a large proportion, which indicated that it had been added to such an extent as would obtain in normal ingot manufacturing practice. In one instance—viz., the main under-carriage strut from the Me.110 (Report No. 49)—titanium oxide inclusions were found to be present in the microstructure, which suggested the possibility that this particular element had been employed as a deoxidiser. There were also traces of titanium in the shock absorber strut from the Junkers 88 (Report No. 26).

Steel-making Process

The indications were that all these steels had been made by the basic electric furnace process, although the possibility that a process involving a final melting in a high-frequency furnace could not be ruled out.

The inherent grain size, as determined by the McQuaid Ehn method, was, generally speaking, of the fine-grained type. It was reasonably consistent in the samples examined, with the exception of the take-off hook, which exhibited a mixed grain of 1 to 6 and the portion of the wing root joint fitting

TABLE III.—COMPOSITION AND MECHANICAL

Report No.	Component.	Aircraft.	Composition, %. C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo	Cu	Other Elements.
26	UNDERCARRIAGE PARTS Shock absorber strut	Junkers 88	0·23	0·45	0·64	0·004	0·005	0·02	0·94	0·25	0·10	Ti 0·003 Al 0·063
34	ASSISTED TAKE-OFF HOOK	Heinkel III	·265	0·32	0·63	0·007	0·033	nil	1·01	0·25	0·14	O_2 0·004 N_2 0·009
112	PORTION OF WING ROOT FITTING	Heinkel III,H6	0·23	0·40	0·66	0·008	0·013	0·05	0·95	0·14	0·11	O_2 0·001 N_2 0·003 H_2 0·0001
49	MAIN UNDER-CARRIAGE STRUT Axle and knee piece	Messerschmitt 110	0·26	0·39	0·64	0·004	0·010	0·14	0·98	0·20	—	—
	Retraction bracket		0·29	0·35	0·71	0·005	0·013	0·09	0·89	0·18	—	—
51	CORNER CASTING	Messerschmitt 110	0·24	0·41	0·61	0·005	0·010	0·07	0·92	0·23	0·14	—
53	V CONNECTION PIPE FROM CENTRE SECTION SPAR	Messerschmitt 110	0·28	0·44	0·59	0·008	0·016	0·10	0·99	0·40	0·17	—
65	UNDERCARRIAGE SUPPORT Head	Messerschmitt 109	0·26	0·40	0·72	0·011	0·015	0·20	0·83	0·13	0·18	Al 0·08
	Foot		0·19	0·49	0·65	0·014	0·012	0·11	0·89	0·24	0·18	V 0·05 Al 0·02
	Torsion Links: Upper		0·23	0·44	0·66	0·018	0·010	0·12	0·86	0·18	—	V 0·05
	Lower		0·23	0·42	0·68	0·015	0·009	0·16	0·91	0·19	—	V 0·05
66	UNDERCARRIAGE BRACKET (Port)	Messerschmitt 109	0·25	0·42	0·69	0·009	0·012	0·08	0·98	0·12	0·10	Al 0·08

(Report 112) which also gave a mixed grain of 1 to 2 and 5.

Cleanness

The castings were all moderately clean from the standpoint of inclusions with the exception of the take-off hook where the lower quality was again evinced.

Microscopic Examination

Examination of the structure indicated that all the components were in the hardened and tempered condition, and that this heat-treatment had been carried out satisfactorily. The only criticism which could be made was with regard to one of the torsion links from the under-carriage strut of the Messerschmitt 109, in which there were indications of over-heating during the hardening operations. In a limited number of instances there were internal microscopic cracks which appeared to be associated with inclusions. (See Table II page 8.)

Mechanical Tests

Mechanical test-pieces have been cut from the castings and the test results are given in Table III., together with an indication of the locations of the test-pieces.

The elongation values obtained on castings of a given tensile strength varied rather widely, and in some instances they were as high as might have been expected from wrought articles conforming to British Aircraft Specifications. The high degree of purity in some of the German components was so marked that an analysis of the mechanical test results considered in conjunction with this has been abstracted and is set out in Table IV.

There was necessarily considerable variation of the test-piece size which had been governed by the cross-sectional area available. The form of the test-piece was chosen to give results as regards elongation which were, or closely approximated to, an effective gauge length of four times the square root of the cross-sectional area.

TABLE IV.—ANALYSIS OF MECHANICAL TEST RESULTS.

Report No.	Aircraft.	Component.	Tensile Strength, Tons/sq. in.	El., %.	S., %.	P., %
49	Messerschmitt 110	Knee-piece	77·0	9	0·005	0·013
49	"	Axle	75·0	8	0·004	0·010
26	Junkers 88	Shock absorber strut	72·7	17·3	0·004	0·005
65	Messerschmitt 109	Torsion link	67·0	16·5	0·018	0·010
66	"	Undercarriage bracket	66·1	12·8	0·009	0·012
51	Messerschmitt 110	Corner casting	66·0	23·5	0·005	0·010
65	Messerschmitt 109	Head	61·0	14†	0·011	0·015
34	Heinkel 111	Take-off hook	59·2	18·3	0·007	0·033
112	Heinkel 111 H6	Portion of wing root fitting	56·9	20·0	0·008	0·013
53	Messerschmitt 110	V connecting piece from centre spar section	52·9	24	0·008	0·016
65	Messerschmitt 109	Foot	52·6	17·5	0·014	0·012

† Broken outside the middle half of test-piece.

PROPERTIES OF CAST STEEL COMPONENTS.

Test-piece Location.	Test-piece Dimensions.	Mechanical Tests. L.P. Proof Stress. Tons/sq. in. 0·1 %.	0·2 %.	0·5 %.	Y.P. Tons	M.S. sq.in	Elongation, %.	R.A. %.	Izod, Ft.-lbs.	Hardness.
Connecting piece	0·050 in. × 0·078 in.	—	—	—	67·9	69·5	7·5 (8 in. GL) 3·0 (2·4 in. GL)	—	—	—
Shock absorber strut	0·050 in. × 0·072 in.	Slightly 36·0	57·2	defective. 61·6	66·4	—	72·2	17·3 (0·75 in. GL) 7·0 (2 in. GL)	—	—	302/321 Brinell
Body	1·1 in. G.L. × 0·3115 in. dia.	Bend ½ in. × ¾ in. section. Radius ½in.—101° cracked.				59·2	18·2	50·0	35, 28, 29	271/306 VPN
Hook Weld metal										226/262 VPN 204/287 VPN
Horizontal portion of T.	0·177 in. dia.	—	—	—	—	53·7	56·9	20·0	54·0	—	255—269
Axle	Gauge length = $4\pi\sqrt{\text{sect. area}}$	—	—	—	—	—	75·0	8·0	25·5	—	327/354 VPN on casting
Knee piece	As above	—	—	—	—	—	77·0	9·0	25·0	—	366 VPN
Retraction bracket generally	—	—	—	—	—	—	—	—	—	--	324/336 VPN
Casting	0·137 in. × 0·145 in.	—	—	-	—	61·5	66·0	23·5 $4\sqrt{A}$	55·0	--	302/311 Brinell
Parallel to one arm of V	0·137 in. dia.	—	—	—	—	45·9	52·9	24·0	67·0	--	269 Brinell
Parallel to main bearing	Tensile, 0·357 in. dia. × 1½ in. G.L. Izod, 10 mm. sq.	—	—	—	—	—	61·0	14·0 OMH	46·0	34, 38	286 Brinell Uniform over casting
From axle portion	Tensile, 0·1 in. × 0·625 in. × 1 in. G.L. Izod: Avery test-piece, ½ in. × ⅜ in.	—	—	—	—	—	62·6	17·5	43·4	15, 15 (Actual) Izod equivalent 70	300 VPN on casting
Flange portion of upper link	Tensile, 0·125in. × 0·5in 0·1 in. G,L. Izod, ½ in. × ⅜ in. Avery test-piece	—	—	—	—	—	67·0	16·5	35·0	12, 11, 12½ (Actual) 47/51 Izod equivalent	300 VPN on both castings. Uniform
Front rib	0·60 in. × 0·20 in. × 2 in. G.L.	50·5	59·4	60·3	61·2	—	66·1	10·0 (2 in.) $\frac{12\cdot8}{4\sqrt{A}}$	--	—	—

The range of tensile strength from 52–77 tons per sq. in. is comparable with that covered by wrought alloy steel in British practice, whilst the elongation shows rather wide variations.

There are instances where, although the order of the strength is similar, the degree of ductility is outstanding. This was exemplified by the corner casting (Report 51) with a tensile strength of 66 tons per sq. in. and an elongation of 23·5%, and the shock absorber strut (Report 26) with a tensile strength 73 tons per sq. in. and an elongation of 17·3%. These two particular components had each a low sulphur and phosphorus content, and it would be observed that there was a marked trend to employ the purer material in those components which possess the higher tensile strength.

When considering the case of the foot casting (Report 65), which had a relatively low ductility, having due regard to the tensile strength, it should be borne in mind that the carbon content of this particular component (0·19) was the lowest of the series.

In only a limited number of cases had impact tests been carried out, and these showed the material to be tough, but the data were insufficient to enable any detailed conclusion to be drawn.

Welding

The only welded casting was the take-off hook. Analysis of the deposited metal revealed it to be of the same type of composition as the body of the cast-

TABLE II.—RESULTS OF EXAMINATION OF CAST STEEL COMPONENTS (*Continued from page 5*)

Report	Component.	Aircraft.	Micro Examination.	Inclusion Examination.	McQuaid-Ehn Grain Size
26	UNDERCARRIAGE PARTS Shock absorber strut	Junkers 88	Acicular structure of tempered martensite. Slight dendritic segregation indicated by uneven response to etching	Rounded inclusions few in number. Indicative of good quality basic steel. Probably electric-arc furnace process. There is a possibility that the acid H.F. may have been used	5
34	ASSISTED TAKE-OFF HOOK	Heinkel 111	Small dendritic grain structure consisting of ferrite and sorbitic pearlite. Decarburisation on all cast surfaces to depth of 0·027 in. Complete decarburisation to depth of 0·006in. Many fine cracks in sorbite situated in inter-dendritic area. Some cracks associated with inclusions. *Weld Metal:* Finely dispersed sorbite pearlite with small areas of ferrite. Decarburisation at outer surface to depth of 0·006 in. *Junction:* Coarse structure. Decarburisation to depth of 0·006 in.	Fairly dirty random distribution of small globular oxides and silicates; few small sulphides and occasional larger slag inclusons. Tendency to group formation of inclusons—slight segregation of sulphides and oxide sulphides adjacent to unsoundness. Weld metal cleaner than parent metal—small globular sulphides and silicates	1—6 5
117	PORTION OF WING ROOT FITTING	Heinkel 111—H6	Hardened and tempered structure. Fine-grained sorbite	Inclusion count—30; very few inclusions	1—2 and 5
49	MAIN UNDERCARRIAGE STRUT Axle and knee piece	Messerschmitt 110	Fine crystal structure consisting of dense sorbite having a mottled appearance, indicative of the cast dendritic pattern. A number of inter-dendritic cracks were found to be associated with inclusions	Slightly dirty random distribution of small angular and globular oxides and silicates and a few larger mono-phased sulphides and angular titanium inclusions	6— 8 mainly 6
	Retraction bracket		Similar structure to axle and knee-piece casting	Similar to axle and knee-piece casting	Not examined
51	CORNER CASTING	Messerschmitt 110	Hardened and tempered condition	Inclusion count value:—27	5 and 8
53	V CONNECTION PIECE FROM CENTRE SECTION SPAR	Messerschmitt 109	Hardened and tempered structure. Sorbite with intermingled ferrite. Slight coring	Inclusion count—30	4—6
65	UNDERCARRIAGE SUPPORT Head	Messerschmitt 109	Fine-grained close sorbite with some intermingled ferrite	Small number of globular sulphides and silicates, having a random distribution. Clean for basic E.F. process	7
	Foot		Fine-grained sorbite with some intermingled ferrite	Few inclusions. Steel clean	4
	Torsion Links: Upper Lower		Both castings have a sorbitic structure. One was fine-grained, but the other was rather coarse—appeared to have been slightly overheated in treatment	Very few small inclusions. Steel clean	3—5
66	UNDERCARRIAGE BRACKET (Port)	Messerschmitt 109	Tempered martensite slightly lacking in uniformity, due to differential response to heat-treatment and etching. Crack is a pocket of unsoundness 0·16 in. deep × 5 in. thick. Oxidised and decarburised in vicinity of crack	Inter-dendritic distribution. Indicative of good quality basic electric furnace steel	5

ing. Actually, the chromium content was somewhat higher, and the carbon slightly lower than the parent metal. Microscopic examination showed that there was a good junction between the weld metal and the casting; the former being the cleaner metal.

General Remarks

Summarising, the investigations had indicated the attainment of a high degree of perfection in the production of these aircraft castings, which could only have been attained by prolonged development of technique, not only from the point of view of design, but of the whole manufacturing operation.

A noteworthy feature was the uniformity of the type of steel employed—that is, a 1% chromium 0·25% molybdenum steel. The carbon content varied from 0·19 to 0·29%, but the other constituents were normal with the exception of sulphur and phosphorus, which were of such a low order as to warrant the conclusion that they had been adopted as the result of considerable experience.

Illustrations

The various components are illustrated in the relevant sections (see Table I).

Sections XII, XIII and XIV will follow in succeeding issues.

The Hardness Test as a Means of Estimating the Tensile Strength of Metals

IN the aircraft industry, an indentation test is frequently used not only to determine actual hardness, but also as a means of estimating the tensile strength of materials. The various machines now available for this form of test are capable of giving reliable results, but owing to varying conditions of test and other causes, the results may differ considerably from values obtained by the Brinell test. This fact is generally recognised, and the British Standards Institution has published a specification (B.S. No. 860–1939) giving an approximate comparison of hardness scales.

Data discussed recently by Taylor* are based on hardness tests made strictly in accordance with B.S. specifications for hardness testing, using Brinell and pyramid diamond (Vickers) machines. The relationship between Brinell and diamond pyramid values are dealt with on the basis of hardness determinations made by the two methods, on identical sections of wrought steels, aluminium- and magnesium-base alloys, copper alloys, and high-nickel alloys. The data indicate that for almost all materials the pyramidal diamond tests give higher values of hardness than the Brinell test. The values may be up to 30% higher than the Brinell, when assessed as a function of the Brinell hardness value

$$\frac{V_H - B_H}{B_H} \times 100$$

Estimation of maximum tensile strength from hardness values is discussed by the author in detail. It is emphasised that for any class of material it is necessary to possess a great number of actual values of hardness obtained for material of known tensile strength, if a forecast is to be given with a fair degree of confidence. The relationships obtaining in various types and forms of steel and non-ferrous materials are illustrated by a series of diagrams showing hardness and experimentally determined maximum tensile strength. The extent to which these provide data for calculation of strength from hardness is critically discussed, with particular reference to factors influencing the validity of the conversion in the respective materials.

* W. J. Taylor, *Jour. Roy. Aeronautical Soc.*, 1942, vol. 46, pp. 198-209.

Refractories in War-Time*

By T. W. Howie

In this review attention is drawn to the development of the stabilised dolomite brick as a substitute for magnesite brick in metallurgical furnaces. The possibility of producing a forsterite brick from British raw materials is suggested, and the application of temperature control to open-hearth furnace roofs is discussed.

THE trend of refractories research is of necessity affected by war-time conditions. It has become imperative to develop substitutes for materials which were either imported from countries now under Axis control, or which now would use shipping space which is needed for more essential purposes.

In a short review of this nature it is impossible to touch on more than a few of the latest developments in refractories, but if it succeeds in drawing attention to some of the more-important developments it will be considered to have served a useful purpose.

Dolomite Bricks

The stabilised dolomite brick is perhaps the most important single development of the past few years. In fact, it is safe to say that if it were not for the stabilised dolomite brick the output of steel from both the basic open-hearth furnace and the basic electric-arc furnace would have been seriously jeopardised, due to the incidence of war. It is true that the stabilised dolomite brick was first used in 1934, and since then has been used almost exclusively in basic open-hearth furnace bottoms by certain steel plants, but it had not been applied at all generally as a substitute for magnesite bricks before the start of the war. The details of the stabilisation and manufacture of these bricks have been recently discussed by Swinden and Chesters.[1] Raw dolomite, which occurs in various areas of England and Wales, is stabilised by firing in rotary kilns with serpentine and dicalcium-silicate stabilisers, according to the reaction:

$$\underset{\text{Dolomite}}{6(CaCO_3MgCO_3)} + \underset{\text{Serpentine}}{3MgO.2SiO_2.2H_2O} \longrightarrow 2(3CaO.SiO_2) + 9MgO + 2H_2O + 12CO_2.$$

Thus, a properly prepared clinker from the rotary kiln consists of tricalcium silicate and magnesia. It will be appreciated that this reaction calls for a considerable amount of control to prevent either free lime, which causes hydration, or dicalcium silicate, which may dust, being present. Actually, the presence of a small amount of dicalcium silicate has no deleterious effect, provided a small amount of stabiliser (B_2O_3.P_2O_5, etc.) is added in the original batch to prevent β—γ dicalcium-silicate inversion. Bricks are made by grinding, pressing and firing the clinker so produced.

The stabilisation of dolomite by materials other than serpentine has been extensively investigated by the British Refractories Research Association,[2] and application of this work may lead to improvement on dolomite bricks as we now know them. The main limitation of the stabilised dolomite brick is its low thermal-shock resistance, but it is now being used with complete success in unexposed positions in basic open-hearth furnaces, basic electric-arc furnaces, and various other types of metallurgical furnaces.

The possibility of using the orthosilicates of the alkaline earths (i.e., $2CaO.SiO_2$, $2SrO.SiO_2$ and $2BaO.SiO_2$) as refractory materials has recently been reviewed.[3]

Semi-stable dolomite bricks, i.e., bricks made from fired dolomite, and in which the lime is prevented from hydrating by a coating of flux, have been produced.[4] There are certain difficulties in their manufacture, but they have a higher spalling resistance and a slightly higher slag resistance than stabilised dolomite bricks. They are being used successfully in fixed basic open-hearth furnace backwalls, and in basic electric-arc furnace sidewalls, giving a life equal to chrome-magnesite bricks in each case. These bricks may be stored for a considerable time if boiled in tar, one such brick having been stored in the author's laboratory for six months before it showed signs of crumbling. A more general application of this type of brick would relieve the chromite and magnesite situation considerably.

Magnesite and Chrome-Magnesite Bricks

Most of the magnesite-producing countries, e.g., Austria, Manchukuo and Greece, are now under Axis control. Magnesite bricks have been largely replaced by the stabilised dolomite brick described in the previous section. Where magnesite bricks are still considered essential, bricks made from magnesia extracted from sea-water by the Chesny process are being used in this country. This process is also being actively developed in the United States,[5] where a plant has recently been completed to produce 40,000 tons of magnesia per annum.

It has long been appreciated that although magnesia is more resistant to slags high in iron oxide than all the common oxides used as refractories, the properties of magnesite bricks are largely controlled by the properties of the bond. Birch[6] has applied the lime-alumina-silica equilibrium diagram to the study of the bond, and has correlated the behaviour of the bricks with the properties of the bond, assuming that the iron oxide is present as magnesio-ferrite ($MgO.Fe_2O_3$). His results are valuable, but it is probable that, with synthetic magnesite at least, iron oxide is definitely present in the bond and has a very marked influence on its properties. It is considered that more data on the system lime-alumina-silica-iron oxides are necessary before any accurate correlation of the behaviour of magnesite bricks with the properties of the bond can be attempted. Data on a section of this system have been published.[7]

In this country there are other demands on our synthetic magnesite production, and the general policy is to use as few magnesite bricks as possible in metallurgical furnaces.

There are no very large deposits of chromite in this country, but recently the use of Shetland chromite in the manufacture of chrome-magnesite bricks has been discussed at length.[8] This ore has been previously considered unsuitable for the manufacture of refractories because of its high silica content. The silica is present as serpentine in the gangue associated with the chromite, and it was found to be a very pure serpentine which yielded forsterite ($2MgO.SiO_2$—melting point 1,910° C.) on firing with magnesia. Chrome-magnesite bricks made, using Shetland chromite, have a relatively low bursting expansion in contact with iron oxide, and are being used successfully in all types of furnaces. Using Shetland chromite, it is thus possible to produce an "all-British" chrome-magnesite

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* A communication from the Central Research Department, The United Steel Companies Limited, Stocksbridge, near Sheffield.

1 T. Swinden and J. H. Chesters. *J.I.S.I.*, 144 (2), 105-118 (1941).

2 J. R. Rait, A. T. Green and H. J. Goldschmidt. *I.S.I. Special Report No.* 28, 95-99 (1942).

3 G. E. Seil and Staff. *J. Amer. Ceram. Soc.*, 24, 1-19 (1941).

4 T. Swinden and J. H. Chesters. *loc. cit.* W. J. Rees, *I.S.I. Special Report No.* 28, 101-102 (1942).

5 Anon. *Rock Products*, 44 (12), 60 (1941).

6 R. E. Birch, *J. Amer. Ceram. Soc.*, 24, 271-280 (1941).

7 J. F. Schairer. *J. Amer. Ceram. Soc.*, 25, 241-274 (1942).

8 T. R. Lynam, J. H. Chesters, T. W. Howie and A. H. Jay. *Trans. Brit. Ceram. Soc.*, 41, 27-45 (1942).

brick, and Table I shows the properties of such a brick compared with those of an Austrian chrome-magnesite brick. The test methods used are those described by Chesters.[9] It is to be hoped that, after the war, the research on home-produced basic refractories is energetically followed up so that we may not be dependent upon foreign supplies of these essential materials.

In Germany, where there are adequate supplies of magnesite from Austria, and a definite shortage of chromite, it is interesting to note[10] that attempts are being made to develop straight magnesite bricks of high thermal-shock resistance to replace chrome-magnesite bricks.

TABLE I.
COMPARATIVE PROPERTIES OF
"ALL-BRITISH" AND AUSTRIAN CHROME-MAGNESITE BRICK

	Chrome-Magnesite Brick made from Shetland Chromite and Sea-water Magnesite.	Austrian Chrome-Magnesite Brick.
Porosity (%)	26·6	21·1
Bulk density (grm. per c.c.)	2·74	3·13
Specific gravity (by porosity)	3·73	3·97
Cold-crushing strength (lb. per sq. in.) on end	1,990	3,460
Permeability (c.g.s.), perpendicular to 9 in. × 3 in. face—through one skin	0·036	0·046
After expansion (%), 2 hours at 1,500° C.	0·7	0·3
Refractoriness under load (25 lb. per sq. in.), maintained at 1,600° C. for 1 hour	5·7% deformation	4·0% deformation
Spalling resistance index	30+	30+
Bursting expansion (%), heated for 1 hour at 1,600° C. with 100 grm. mill scale	12·5	23·6

Forsterite Bricks

An increasing amount of attention is being paid to refractories of the forsterite type, particularly in Russia. Forsterite proper is the mineral $2MgO.SiO_2$, and occurs naturally as olivine. It can also be produced by firing magnesium silicates such as talc, serpentine and stearite with magnesite. In view of the present shortage of chromite and magnesite in this country, it should be possible to make satisfactory forsterite bricks from serpentine rock, which occurs in the Shetland Islands and other parts of the Western Highlands. Such trials as have been made in this country with forsterite bricks, using Norwegian olivine, have given satisfactory results in backwalls of basic open-hearth furnaces when substituted for chrome-magnesite bricks. It is probable that steel output would suffer if chrome-magnesite bricks were replaced by silica bricks, and it is thought that the use of forsterite bricks would obviate this. In one case[11] it has been shown that forsterite bricks gave a life five times that of silica bricks in basic open-hearth furnace backwalls, and it has also been used[12] to replace magnesite in sloping backwalls. Unfired dunite (a rock consisting essentially of olivine and serpentine) is also being used successfully in Russia.[13] It is thought, too, that forsterite bricks could be employed successfully in basic electric-arc furnace sidewalls. As the average serpentine rock requires about 20% added magnesite to convert it to forsterite, and the chrome-magnesite brick contains 30—40% of added magnesite, the use of forsterite bricks would reduce both the magnesite and chromite at present used for the manufacture of chrome-magnesite bricks.

Silica Bricks

It has been said that silica bricks have not improved in the last 20 years. This is very far from being true, because there have been considerable improvements both in their manufacture and in the appreciation of the factors involved in their correct usage. A comprehensive study of the factors influencing the durability of basic open-hearth furnace roofs has been published by the Open-Hearth Refractories Panel.[14] One roof was examined, and was followed through from a study of the raw quartzite used in its manufacture to the examination of the used bricks after the campaign had finished. The temperature of the roof was recorded continuously by means of a radiation pyrometer sighted through the backwall on to the centre of the roof, and by thermocouples at various depths in the roof. The seasoning, or maturing, of the roof seemed to be complete after about two weeks. During this maturing period the silica in the hot face of the brick is converted to cristobalite, and a certain amount of fluxes, CaO, iron oxide, etc., penetrate the brickwork, and together with the temperature gradient through the brickwork produce the zoning characteristic of used silica roof brick. The most significant feature of this is that although the hot face has picked up a relatively large amount of fluxes, a cone *cut* from the hot face may melt at a temperature actually 20° to 30° C. higher than that of the original brick. This is probably due to the very stable network of cristobalite formed as a result of the maturing, and emphasises the desirability of maturing the roof in the early stages of the campaign. A typical microstructure of the hot face of a silica roof brick is shown in Fig. 1. This fact also explains how a roof can be held at, say, 1,680° C. for relatively long periods without causing any damage, and it is suggested that more damage will be done by the roof running on being held for a few minutes at, say, 1,740° C. than will be done on holding continuously at 1,680° C.

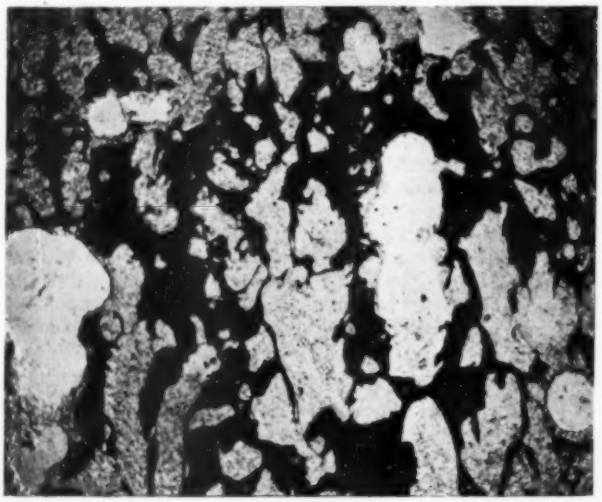


Fig. 1.—Hot face of silica brick from basic open-hearth furnace roof showing cristobalite (light), iron-rich glass (dark), and a few rounded pores.

This fact shows the value of controlling the temperature of the roof by a pyrometer. The furnace can then be run as economically as possible without the risk of damaging the roof by melting it. This type of control is used quite extensively in the United States, and is beginning to find favour in this country. It will no doubt lead to increased roof life.

Similar data on electric-arc furnace roofs would be of interest because such roofs as have been examined, to the author's knowledge, behave rather differently to the basic open-hearth roof in that the cristobalite zone does not appear at all. Whether this is due to the reducing nature of the atmosphere on the roof causing excessive slagging and thus preventing maturing, or to the temperature being lower than 1,470° C. is at the moment a matter of conjecture.

Fireclay Bricks

Although there has been relatively little published data on fireclay refractories recently, considerable improvements have been effected by closer control and in the application

9 J. H. Chesters, *Iron Age*, 147, 33, Feb. 6. 47, Feb. 13 (1941).
10 H. Kalpers, *Bergbau*, 54, 54-57 (1941).
11 P. Egorov, *Stal*, No. 7, 47-48 (1940).
12 A. Bereshnoi and V. Gulyaev, *Stal*, No. 8, 18-27 (1940).
13 Y. V. Klyucharov and A. G. Marants, *Tr. Vses. Inst. Ogneupurov*, 18, 32-53 (1939).
14 *J.I.S.I.*, 141(2), 203-271 (1941).

of modern methods, e.g., de-airing, in their manufacture. Blast-furnace refractories have been discussed by Kraner[15] and it is confirmed that attack by carbon monoxide and alkalies are the main factors in the deterioration of the stack brickwork. He also considers that the hearth bricks should be more refractory and less porous than those at present used. Blast-furnace refractories have also been discussed in detail by Rigby and Green.[16] It is thought that war-time conditions have led to an increase in break-outs in blast furnaces, and it may be that the adoption of carbon bricks for the hearth will obviate this. Rigby and Green[17] have shown that it is possible to produce a carbon brick on a laboratory scale equal to German carbon brick, which is used widely for this purpose in that country. The use of carbon bricks has also been advocated in the United States.[18] Experimental carbon bricks produced in this country have been successfully used in the iron runners from blast furnaces.

Due to the necessity of using all types of scrap at the present time, excessive damage to checker bricks in open-hearth furnaces has been experienced due to the volatilisation of zinc from galvanised scrap, etc., and the strong fluxing action of zinc oxide on the checker brickwork. An investigation of this problem[19] suggests that high alumina (42% Al_2O_3) bricks are more likely to give good service in this position when high concentration of zinc oxide are likely to be encountered.

15 H. M. Kraner. *J. Amer. Ceram. Soc.*, 25, 311-320 (1942).
16 G. R. Rigby and A. T. Green. *I.S.I. Special Report*, No. 28, 103-131 (1942).
17 G. R. Rigby and A. T. Green. *Trans. Brit. Ceram. Soc.*, 41, 44-147 (1942).
18 F. J. Vosburgh. *Iron and Steel Engineer*, 17, 68-72, 1940.

General

It is thought that considerable improvements could be made in the use of refractories if a certain amount of standardisation in both the shape and size of bricks could be effected. Too often the size of bricks is controlled by a drawing office with little appreciation of the problems involved in its manufacture and use. This is especially the case in respect of electric-arc furnace roof bricks and in casting pit refractories, where each individual firm uses, in itself, a great variety of shapes and sizes which could easily be reduced without loss of efficiency. Standardisation would have the further advantage that the manufacturer, with fewer moulds, etc., to control, could divert this control to the manufacturing processes themselves and so produce a better and, incidentally, a cheaper article. Certain efforts have already been inaugurated in this direction.

In conclusion, the author would like to thank Dr. T. Swinden, Director of Research, The United Steel Companies Limited, for permission to publish this review.

19 J. H. Chesters and T. W. Howie. *Trans. Brit. Ceram. Soc.*, 40, 33-39 (1941).

Progress of Copper and Copper Alloys

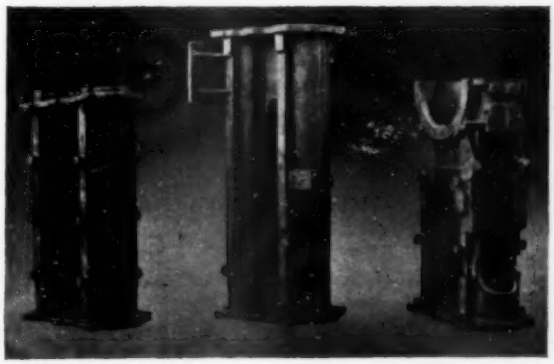
By J. W. Donaldson, D.Sc.

War-time demands have evolved economies in the use of copper and its alloys, and because of shortages in certain elements normally used in copper alloy compositions, changes and substitutions have become necessary for many purposes. Developments, therefore, have been concerned with modifications according to the availability of materials and the service requirements of the products, and it is these factors with which this review deals.

THE advent of the war, and developments connected with it, has caused a very large increase in the use of non-ferrous metals and alloys. Of the four metals, copper, nickel, aluminium and lead, perhaps the most important in war-time is copper, due to the large amount used in the manufacture of small arms ammunition. The ever-increasing armament programme of the United Nations has made a tremendous demand on copper and its alloys, a demand which in the last year the present output of copper has found a difficulty in meeting, with the result that there has developed a decided shortage of this metal. This shortage has necessitated the recovery and utilisation of all copper and copper alloy scrap, and also the salvage of all available articles made in copper and its alloys.

Recent events have also produced a decided shortage of tin, and the scarcity of this metal has introduced certain economies in its use, not only for the production of tin-base alloys but also for the production of copper alloys containing tin. New specifications have had to be prepared for the tin bronzes, and the use of certain of these bronzes have had to be discontinued and the use of others curtailed, and other alloys substituted in their place. Shortage of copper and other metals has also reduced the number of copper-base alloys, both cast and wrought, in general use, and this has been done by the issue of a number of emergency and war-time specifications.

A review, therefore, of development and progress with regard to copper and its alloys at the present time must deal largely with changes and substitutions which have had to be made on the alloys in general use rather than with the development of new and improved alloys. There



Courtesy of Vickers-Armstrong, Ltd.

Some castings in P.M.G. metal.

have been, however, certain developments both in the extended application of existing alloys for high-duty purposes, particularly in the war industries, and also in experimental and research investigations, although very little of the latter work has been made available, due to the restrictions in force with regard to the publication of such work.

Pure Copper

During the last two or three years there has been an increased use of oxygen-free high-conductivity copper, and a continual development in the melting, casting and fabrication of copper in all its forms with a view to obtaining better material and also to increasing production. Pure

copper, the larger proportion of which is used in the wrought form as plates, rods, sheets, strips, tubes and wire, still finds its largest applications for electrical purposes where a high-conductivity metal is essential. Tube manufacture also continues to call for a large amount of copper in the aircraft, automobile, locomotive and marine engineering industries, and in shell manufacture there is an ever-growing demand for copper for such parts as driving rings, etc. A very small proportion of copper is used in its cast condition, but certain copper castings which contain small proportions of chromium, cobalt and beryllium, cobalt and silicon, or nickel and silicon, and which have good conductivity properties, which are susceptible to heat-treatment, and which retain their strength at elevated temperatures, are found to have limited but increasing application in many industries.

For most forms of pure copper British Standard Specifications have been prepared for the various industries. A new specification, B.S. 1035-40, has been issued recently for pure copper. This specification states the requirements for such varieties of copper as cathode copper, electrolytic tough-pitch high-conductivity copper, fire-refined tough pitch high-conductivity copper, and 99·85, 99·75, 99·50% tough-pitch copper.

Brasses and Bronzes

Wrought brasses in the form of plates, rods, strips, sheets, tubes and wire are used in large quantities for a variety of parts in many industries. Their compositions range from an 97/3 copper-zinc alloy used for ammunition caps, through an 83/14 special alloy containing nickel, silicon and aluminium used for aircraft purposes, 70/30 brass used for cartridge cases and condenser tubes, 64/40 brass used for a variety of purposes, 62/37/1 or rolled naval brass to high-tensile brass. All these alloys are specified to British Standard Specification. Recently a new war emergency specification, B.S. 1001-2, has been prepared for high-tensile brass bars and sections and forgings suitable for forging and soldering, and for forging but not suitable for soldering. Until a few months ago there were no British Standard Specifications for brass castings, although such alloys were classified to a certain extent in the United States. In consequence, however, of the present need for economy in the consumption of tin, it was found necessary to prepare war-emergency specifications for two grades of cast brass which could be used as substitutes for gunmetals and other tin-bronzes.

All high-grade bronze castings were made until recently of Admiralty gunmetal 88/10/2, castings for lower grades being made of the 87/9/3/1 and 85/5/5/5 alloys, or of alloys of somewhat similar composition. To economise in the consumption of virgin metals, and to utilise to the best advantage the supplies of bronze and brass scrap available, new specifications have been prepared during the past year which bring into use bronzes of lower tin content than those previously used in Britain. Both the old and new specification for bronzes and brasses are summarised in Table I. For the duration of the war it is proposed that the use of 88/10/2 gunmetal should be severely restricted, and that the 87/9/3/1 alloy should not be used. For high-grade work the 86/7/5/2 alloy is recommended, the 88/10/2 and the 88/8/4 alloys only to be used for very special applications. For general work the 85/5/5/5 alloy is considered suitable where a tin-bearing alloy is essential, but where such an alloy can be dispensed with Type A and B brasses are to be used instead. All the new alloys are to be made from scrap, but where scrap is not available and virgin metals have to be employed, their use is confined to alloys of the 88/10/2 and 88/8/4 types. At the recent annual meeting of the Institute of British Foundrymen the properties of these low-tin gunmetals were discussed by Hudson,[1] and the founding of the Type A and B brasses by Howard[2] and by Arnott.[3]

Until recently phosphor bronzes have been supplied for general engineering and maintenance work as sand castings, or as chill-cast stick, using alloys of high-tin content, such as are specified by the Admiralty specification for phosphor-bronze castings or by the British Standard Aircraft Specification 2 B.8. This last specification has just been replaced by two new British Standard Specifications, 1058–1061. The first alloy specified has tin and phosphorus contents of not less than 10 and 0·5%, respectively, and is recommended for all high-duty work, particularly for aircraft purposes. For other engineering purposes high-tin alloys are considered unnecessary at the present time, and the second alloy specified for such purposes has therefore a much lower tin content, 6·5—8·5%, and also contains both lead and zinc. This latter alloy should be prepared as far as possible from scrap, and where virgin metals have to be employed their use should be confined to the preparation of the higher-grade alloy. In the wrought condition, in the form of bars and rods for general purposes, phosphor-bronze contains 4·5 to 6·5% of tin and 0·02 to 0·4% of phosphorus (B.S. 369), and has a tensile strength of 17/5 to 45 tons per sq. in., according to size.

In 1941 new specifications were also prepared for three lead bronzes, such as are used for bushes and bearings. These leaded bronzes are specified to contain 85/10/5, 80/10/10 and 76/9/15 copper-tin-lead with up to 0·3% of phosphorus.

TABLE I.
BRITISH STANDARD SPECIFICATIONS FOR CAST GUNMETALS AND BRASSES.

Type.	No.	Composition.						Mechanical Properties.	
		Cu.	Sn.	Zn.	Pb.	Ni.	Other Elements.	Tensile Strength, Tons/sq. in.	Elongation, %.
Gunmetal 88-10-2	382 383	Remain	9·5 10·5	1·5 2·5	0·5 max.	1·0 max.	0·15 max.	16·0	8—12
Gunmetal 87-9-3-1	900 901	Remain	8·0 10·0	2·0 4·0	0·5 2·0	1·0 max.	0·50 max.	14·0	8—12
Gunmetal 88-8-4	1021 1022	Remain	7·5 8·5	3·5 4·5	0·5 max.	1·0 max.	0·15 max.	16·0	8—12
Gunmetal 86-7-5-2	1023 1024	Remain	6·0 8·0	4·0 6·0	1·0 3·0	1·0 max.	0·5 max.	14·0	8—12
Gunmetal 85-5-5-5	897 898	Remain	4·0 6·0	4·0 6·0	4·0 6·0	1·0 max.	0·5 max.	12·0	8—12
Brass—Type A	1025 1026	70·0 80·0	2·0 max.	Remain	1·0 4·0	1·0 max.	Fe 0·75 max. Al 0·01 „	11·0	15—20
Brass—Type B	1027 1028	62·0 70·0	2·0 max.	Remain	1·0 4·0	1·0 max.	Fe 0·75 max. Mn 0·25 „ Al 0·25 „	14·0	10—12

Copper-Aluminium Alloys

During recent years there have been considerable developments in the use of copper-aluminium alloys, aluminium bronzes and aluminium brasses, both in their wrought and cast conditions. Advances have been made in the use of aluminium bronze in tube form, where the alloy has a good resistance to corrosion and also resists oxidation well on heating. No standard specifications exist for aluminium bronze in this form, but cold-worked tubes and sheets usually contain 4 to 7% of aluminium, and up to 4% of manganese and/or nickel, and hot-work

1. F. Hudson. *Foun. Trade Jour.*, 1942, vol. 67, pp. 221–230.
2. E. J. L. Howard. *Foun. Trade Jour.*, 1942, vol. 67, pp. 247–248.
3. J. Arnott. *Foun. Trade Jour.*, 1942, vol. 67, pp. 248–249.

forms from 7 to 10% of aluminium, and up to 2% of manganese, iron and nickel. For rods and other forged products a number of D.T.D. specifications have been prepared. For condenser tubes where copper-nickel tubes are not in use, aluminium-brass tubes, 76/22/2, copper-zinc-aluminium, continue to be used in large quantities and gives good service results.

For die castings for which aluminium bronzes are extensively used, alloys containing 9 to 10% of aluminium, 2·5 to 4·5% of iron, and varying amounts of manganese and nickel are in general use. For general sand castings two specifications have just been issued, B.S. 1031-2, Table II. Both these alloys are suitable for high strength, high-temperature castings, and are suitable for replacing tin-bronzes for many purposes. They are also very resistant to sea-water corrosion.

Aluminium bronzes are also finding an increased application for bearings such as bushes and thrust bearings, an alloy containing over 10% of aluminium being best suited for such applications. Aluminium-bronze bearing alloys have a high-compressive strength and a high-impact strength, and are particularly suitable for high-duty service where speeds are slow, although they have also been used satisfactorily with speeds over 1,000 ft. per min.

Silicon Bronzes

In view of the urgent need for tin economy, and the replacement of high-tin content bronzes by alloys free from tin, copper-silicon alloys or silicon bronzes have been made the subject of the War Emergency British Standard Specification 1029-30, Table II. This specification covers such specific alloys as P.M.G. metal and Everdur.

Although good-quality castings in silicon-bronze can readily be prepared by experienced foundries, it was not considered possible to make general recommendations for the substitution of silicon bronze for tin bronze, as in the case of low-grade gunmetals and brass. To give guidance on the foundry technique of these bronzes a panel of the Non-Ferrous Sub-Committee of the Technical Committee of the Institute of British Foundrymen prepared a report dealing with silicon bronzes as casting alloys, and this report was presented at the annual meeting of the Institute in June of this year.[4]

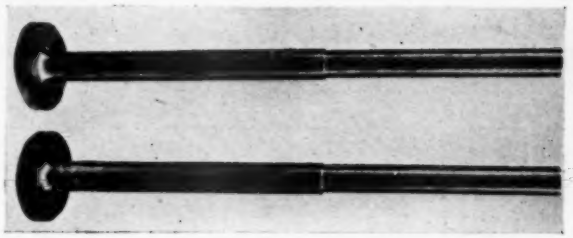
TABLE II.
BRITISH STANDARD SPECIFICATIONS FOR CAST ALUMINIUM BRONZE AND SILICON BRONZE.

Type.	No.	Composition.								Mechanical Properties.	
		Cu.	Al.	Si.	Fe.	Mn.	Ni.	Zn.	Other Elements.	Tensile Strength, Tons/sq. in.	Elongation, %
Aluminium bronze	1031 1032	Remain	8·5 10·5	—	1·5 3·5	1·0 max.	1·0 max.	0·5 max.	0·3 max.	32·0	20·0
High-tensile aluminium bronze	1072 1073	Remain	8·5 10·5	—	3·0 5·5	3·9 max.	3·0 5·5	0·5 max.	0·3 max.	40·0	12·0
Silicon bronze	1029 1030	Remain	—	1·5 5·0	2·5 max.	1·5 max.	—	5·0 max.	0·5 max.	20·0	15·0

Silicon bronzes not only have a high strength and toughness but also have a good resistance to corrosion, and are very suitable for high-pressure work. They are also easily welded both by the oxy-acetylene and electric-arc methods. Where silicon bronzes can be prepared, silicon bronzes are very suitable for replacing high-tin bronzes for many purposes, and their use is therefore being extended. In the casting and machining of such bronzes care must be taken, however, that scrap and turnings are not mixed with other copper-alloy scrap, as silicon bronze is detrimental to the properties of re-melted tin bronze.

For wrought material, a new aircraft specification for aluminium-nickel-silicon-brass bars has just been issued, D.T.D. 319. This alloy contains 81 to 86% copper, 0·7 to 1·2% aluminium, 0·8 to 1·4% nickel, and 0·8 to 1·3% silicon, and has a tensile strength of 30 tons per sq. in., a proof stress of 15 tons per sq. in., and an elongation of 25%, and is to be used only where high strength and corrosion resistance are required.

4. J. Arnott. *Foun. Trade Jour.*, 1942, vol. 67, pp. 206–208.



Courtesy of Vickers-Armstrong, Ltd.

Forged shafts in P.M.G. metal.

Copper-Nickel Alloys

During the last few years little fresh information has been made available with regard to developments in copper-nickel alloys. This is partly due to war-time restrictions on the publication of new investigations and researches, and also on the limitation imposed on the use of the basic metals. So far as wrought alloys are concerned, 80/20 and 70/30 copper-nickel alloys remain the standard alloys for condenser tubes, and show the best all-round corrosion resistance to salt-water.

This is emphasised in a report published recently by the American Society of Mechanical Engineers. Wide application also continues to be made of the wrought-nickel silvers or copper-nickel-zinc alloys in the form of sheets, strips, bars, rods and plates. Most of these are standard alloys, but recently a number of special alloys have been developed for special purposes.

Nickel-silver alloys in the form of castings containing 55 to 65% copper, 10 to 25% nickel, and the remainder zinc are also produced in fair quantity for general purpose values and for many types of fittings. Nickel bronzes, copper-tin-nickel alloys and copper-nickel-silicon alloys, both of which are heat-treatable temper-hardening casting alloys which give tensile strengths from 30 to 40 tons per sq. in., and have Brinell hardnesses approximating to 200, developed some years ago, continue to be used increasingly in many industries, being suitable for replacing both cast and wrought alloys for certain parts. Nickel also continues to be added to a number of copper-tin bronzes in small quantity, up to 1%, when it causes a marked increase in the strength, ductility and hardness.

Copper Bearing Alloys

In normal bearing practice, white bearing metals are cast into shells of steel, cast iron, gunmetal or phosphor bronze. Where no bearing properties are demanded of the shell, it is now recommended that all such shells shall be of steel, cast iron, brass or other tin-free alloy. In all cases where phosphor bronze and gunmetal unlined bearings or bushes are used, alloys of lower tin content than those at present in use have to be substituted.

Tin economy and the necessity for bearings to withstand higher loads and speeds have extended the use of copper-lead bearings, Table III, for connecting rod, crankshaft and main bearings in aircraft and automobile engines. This results from the fact that copper-lead bearings permit of 20 to 25% higher loading than tin-base white metals and are more resistant to wear. They are, however, more susceptible to corrosive action, particularly by petroleum acids, than white bearing metals. It is also necessary to use such bearings in conjunction with hard steel shafts.

TABLE III.
COPPER-LEAD BEARING ALLOYS.

Composition.									British Specification.	American Specification.
Cu.	Pb.	Sn.	Fe.	Zn.	Ni.	Ag.	P.	Other Impurities		
54·5	35/45	0·001	0·20	—	—	—	—	0·30	—	S.A.E. 480
68/72	28/32	—	0·10	—	—	0·4/0·75	—	—	D.T.D. 274	—
69/74	26/31	0·05	0·25	0·10	0·01	1·5	0·01	0·15	—	S.A.E. 48 A.M.S. 4820
68/75	23/27	2/4	0·35	0·10	0·01	0·20	0·01	0·2	—	S.A.E. 481 A.M.S. 4822
67·5/72·5	23/26	4·5/6·0	0·3	0·50	—	—	0·01	0·25	—	A.M.S. 4840
68/75	23/27	2/4	0·10	0·10	1·0	—	0·05	0·10	—	S.A.E. 482
72/76	23/28	2	—	—	—	—	—	0·25	D.T.D. 229A	—
70/79	15/20	6/10	—	—	—	—	—	0·25	D.T.D. 422	—

The greatest handicap to a more general use of copper-lead bearings is in their fabrication in obtaining a good dispersion of the lead and in the-bonding of such alloys to steel shells. Such difficulties have been overcome recently to a certain extent by improved fabricating technique and the manufacture of triplex bearings in which copper-lead alloys are applied to steel shells by powder metallurgy and copper brazing methods, after which tin or tin-base white metals are cast on or sprayed on top. Another triplex bearing consists of a steel shell, coated with a copper-nickel alloy and covered with a lead-base white metal.

Oil-retaining bronze bearings, suitable for bushes and bearings inaccessible to normal lubricating, are also being increasingly used for many engineering parts, and are found to give satisfactory results provided attention is paid to operating loads and speeds.

Bronze Welding

The oxy-acetylene process of bronze welding of both ferrous and non-ferrous metals, which has achieved considerable importance during recent years, has been found to be extremely useful at the present time for fabrication and repair work in many industries. The efficiency of the process depends to a large extent on the type of welding rod used. Bronze-welding alloys usually consist of 60% copper, 40% zinc with small amounts of silicon, or nickel or silicon and tin, and have melting points approximating to 900°–950° C. To obtain lower melting better, and better flowing conditions, other welding bronzes have also been developed recently by adding other elements and certain deoxidisers to 60/40 brass. For the electric-arc welding of deoxidised copper, an alloy of copper and silver containing 0·5 to 1·0% silver has been found to give satisfactory results.

Research Work

Apart from investigations of a more or less theoretical nature dealing with the constitution of copper and its alloys, of which a limited number have been made available during recent years, some investigations of a more practical nature have also been carried out. Experiments by Voce[5] dealt with the softening of hard-drawn high-conductivity copper wire on prolonged heating at 80° C., and Cook and Larke[6] have investigated the impact strength of deoxidised arsenical and non-arsenical, and tough-pitch arsenical and non-arsenical copper in the form of extruded rod and rolled plate. A detailed study has also been made by Cook and Tallis[7] of the effect of progressively increasing amounts of cold-work on the hardness and mechanical properties of seven standard phosphor-bronze alloys in strip form, as well as of their annealing characteristics.

With regard to foundry conditions, extensive tests have been made by Pearson and Baker[8] to determine the influence of shrinkage and of dissolved gases on the incidence of porosity in tin bronze, using a melting and casting technique which permitted very close control of all conditions and yielded strictly comparable test results. The degree of porosity was estimated from density measurements, and tensile tests were made on the castings. Rae[9] has investigated the effect of using fired small arms cartridge cases in the manufacture of three straight brasses containing 62, 59 and 56% copper, three standard leaded brasses and a naval brass, and has shown that certain physical properties of these alloys, more particularly their impact resistance and bending and cold-riveting properties, are impaired due to the introduction of antimony. The use of permanent moulds, and their application to the production of non-ferrous alloys, including gunmetal, brass, phosphor bronze and high-tensile brass, have been investigated by Hudson,[10] and a Sub-Committee of the American Foundrymen's Association have issued a report[11] on "Recommended Practice for Sand-Cast Tin Bronzes," which deals with the moulding, melting and pouring, finishing and chemical control of these alloys.

The corrosion and cavitation of copper alloys have formed the subject of two investigations. In the first of these, results are given by Britton[12] of tests made in railway tunnels for three-and-a-half years on materials that included arsenical copper, cupro-nickel, Everdur, aluminium bronze sheets and cadmium-bronze and tin-bronze wires. These tests have shown that while most of these alloys corroded about ten times as fast as would be expected in the open air they had a superior life to ferrous alloys, including stainless steel. The cavitation tests were carried out by Beeching,[13] using a vibratory apparatus, and included high-tensile brasses, aluminium bronzes, gunmetals and phosphor bronzes. The best results were obtained with aluminium bronze, followed by special high-tensile brasses, while cast gunmetal gave inferior results, and cast Admiralty phosphor bronze a result somewhat similar to cast Admiralty high-tensile brass.

Ilford Document Papers

WAR conditions have greatly increased the practice of photographing documents, and since the advantages of this practice are gradually becoming more fully appreciated there is no doubt that it will continue to be applied on an increasing scale after the war. For this class of work special papers have been developed, and it is of interest to note that Ilford, Ltd., have recently published a useful booklet giving instructions for the use and application of the wide range of papers they manufacture for this purpose.

All Ilford document papers are capable of giving a strong black image combined with clean whites, thus giving the maximum visible contrast. With the exception of a few grades specially coated on thick base, all are on a special document paper base which is thin, yet tough, very uniform in texture, and of a clear white colour. This booklet gives information on the range of papers available, and includes the working instructions. Copies may be obtained on application to Ilford, Ltd., Ilford, London.

5. E. Voce. *J. Inst. Metals*, 1941, vol. 67, pp. 1–8.
6. M. Cook and E. C. Larke. *J. Inst. Metals*, 1942, vol. 68, pp. 1–14.
7. M. Cook and W. G. Tallis. *J. Inst. Metals*, 1941, vol. 67, pp. 49–65.
8. T. F. Pearson and W. A. Baker. *J. Inst. Metals*, 1941, vol. 67, pp. 231–255.
9. J. Rae. *J. Inst. Metals*, 1942, vol. 68, pp. 311–328.
10. F. Hudson. *Foun. Trade Jour.*, 1941, vol. 64, pp. 153–155.
11. F. Hudson. Amer. Foundrymen's Assoc. Convention, 1942.
12. S. C. Britton. *J. Inst. Metals*, 1941, vol. 67, pp. 119–133.
13. R. Beeching. *Trans. Inst. Eng. and Ship. Scotland*, 1941/42, vol. 85, pp. 210–276.

The Iron and Steel Institute

Autumn Meeting in Sheffield

THE Autumn meeting of the above Institute, held in Sheffield on December 10, by arrangement with the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association, and the Sheffield Branches of the Institute of British Foundrymen and the Refractories Association of Great Britain, was a joint meeting with these societies. Following the official business two technical sessions were held, one during the afternoon was devoted to what could be regarded as a symposium on rimming steel, while the other, discussed during the evening, was the Second Report of the Moulding Materials Sub-Committee.

Five papers dealing with rimming steel were submitted. Each of these papers is complete in itself, yet each is complementary to the other. All the papers bear a relation to previous work; indeed, some of them are directly developed from it. They are published by the authority of the Committee on the Heterogeneity of Steel Ingots, a body which, among its other activities, has done much to advance the scientific study of the phenomena associated with rimming steels. Many of the reports issued by the Committee have included work on rimming steel, and their Ninth Report[1] dealt exclusively with it. It will be interesting, therefore, to review the reports up to date.

Rimming Steel

A bibliography on rimming steel is naturally outside the scope of these notes, but it is felt that the importance of the five new papers demands more than a passing reference to the previous work, which probably inspired them and made their production possible. We have, therefore compiled the following few notes relating to the earlier work.

Second Report.[2] A general examination was made of a rimming ingot destined to be made into tubes. This is Ingot No. 24 in the Committee's series.

Fourth Report.[3] Section IV of this report is entitled "Principles Involved in the Making of Rimming Steel." The general characteristics of rimming ingots are indicated, and their typical general heterogeneity is discussed. Attention is drawn to the influence of furnace and pit practice on heterogeneity, with particular reference to the origin of and the control of gases in steel. The role that may be played in the rimming phenomena by hydrogen and other gases dissolved in the molten steel is discussed at length, and the Committee concludes: ". . . it is safe to say that in the present state of knowledge no satisfying explanation of the phenomena associated with the type of ingot known as rimming steel can be regarded as established." Ingot No. 59 was examined and reported on.

Fifth Report.[4] In this report rimming steel ingots are described, first, in a general way, and then classified into "box-hat" true rimming, and rising steel ingots. The way in which the rim blow-holes vary with these different ingots is described, and an indication is given of how steel-making practice might be adjusted to produce the desired type. Two rimming steel ingots were examined by sectioning sulphur-printing and macro-etching, and also by chemical analysis at the standard positions. Ingot No. 61 was made by the acid Bessemer process, and No. 62 in the basic open-hearth furnace. The latter ingot, by the pit sample, contained only 0·02% of carbon and 0·028% of manganese. Section V consists of a study of the influence of varying oxygen and carbon contents in iron upon the position of blow-holes in steel ingots.

Sixth Report.[5] In this report results are given of the examination of Ingots 63 and 64, two ingots of rimming steel made by the basic Bessemer process; and of Ingot 65, an ingot of rimming steel of high purity made by the basic open-hearth process. Other work, published in this report, that bears upon the rimming phenomena is concerned with the determination of oxygen and nitrogen in steel; the effect of gases on the solidification of ingots; and the influence of casting temperature on the position of blow-holes in ingots. (The publication of the details of Ingots 63 and 64 gave rise to a very lively discussion, undoubtedly inspiring further research.)

Seventh Report.[6] In this report Dr. T. Swinden gives the results of a study of composition variation from outside to centre in two rimming steels: (*a*) a billet of open-hearth rimming steel containing 0·16% of carbon, and (*b*) an ingot of basic Bessemer steel, Ingot No. 64, details of which are contained in the Sixth Report. The results of the latter examination showed that as regards carbon, sulphur and phosphorus there was a definite fall as one traversed from the outside of the ingot through the rim. At the junction of the rim and the core there was a sudden rise to a peak, which was well above the average composition of the steel, following which there was a flattened curve with a secondary peak. In the case of manganese there was a small but definite reduction in the content through the rim, followed by a rise at the junction of the rim and core, beyond which the manganese content was fairly constant. It was pointed out that the manganese content did not show the variations necessary to accommodate the variation of sulphur in the form of manganese sulphide.

Ninth Report.[1] In this report the Committee discuss the theory of rim formation, and give notes on typical practice in the manufacture of rimming steel in British steelworks. In Section II of the Report, Principal C. A. Edwards reviews the theoretical discussion of the process of solidification of iron-carbon-oxygen alloys put forward by Hultgren and Phragmén. He brings out the more salient features of their work, and also gives an outline of some of the views he has himself expressed on the subject.

The next Section, on further studies of the composition variation of rimming steel from outside to centre, is a continuation by Dr. Swinden of his work published in the Seventh Report. He gives details of a further examination of the same basic Bessemer ingot, including data on inclusions, Brinell hardness and oxygen and nitrogen contents. Also a detailed study is made of a bloom of rimming steel, cross sections at points corresponding to the top, middle and bottom of the ingot being examined by microscopical examination, chemical analysis, including oxygen, hydrogen and nitrogen.

Section IV consists of notes on the manufacture of rimming steel at nine British works, and a general survey by Mr. J. Mitchell, who describes the characteristics of rimming steel and the rimming action, reviews the differences in practice, and submits conclusions on the manufacture of rimming steel in Great Britain.

1 Ninth Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute, Special Report No. 27.
2 Second Report on the Heterogeneity of Steel Ingots. *Inst. Jnl.*, 1928, No. 1.
3 Fourth Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute, Special Report No. 2.
4 Fifth Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute, Special Report No. 4.
5 Sixth Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute, Special Report No. 9.
6 Seventh Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute, Special Report No. 16.

The New Papers

No. 12, "Rimming Steel." Comparative study of three ingots received from Soc. Anon. des Hauts Fourneaux, Forges et Acieries de Denain et d'Anzin, at Denain, France. By J. Mitchell.

No. 13, "An Ingot of Rimmed Steel made by the Basic Open-Hearth Process." By D. Binnie, Ph.D.

No. 14, "Rimming Steel." Report on four ingots of basic Bessemer steel. By J. Mitchell.

No. 15, "Rimming Steel." Additional studies of the composition variation from outside to centre. By T. Swinden, D.Met.

No. 16, "A Note on Diffusion in Rimming Steel on Soaking at about 1,300° C." By T. Swinden, D.Met., and W. E. Stevenson, A.I.C.

Paper No. 12. This work, by Mr. Mitchell, is a direct progression from that carried out with Ingots 63 and 64. The interest that was aroused and the discussion that was provoked by the publication of the Committee's work on these ingots (in the Sixth Report) encouraged them to obtain further ingots from the same source. Two ingots were made in 1939, in the presence of the Committee's observers, and in this paper Mr. Mitchell compares them with Ingot No. 64. The two ingots made in 1939 have been numbered 9368 and 9369. For all three ingots data are available of steelmaking practice, there are sulphur prints and macro-etchings of centre-sections, analyses at the Committee's standard positions, and detailed analyses including oxygen and nitrogen determinations, of a strip at the middle of the length from the edge to the centre of each ingot.

All three ingots were cast in similar big-end-up moulds, and the ingots weighed approximately 4½ tons. Examination of the sulphur-prints and macro-etchings showed that the ratio area of rim/area of core was, for Ingot 64, much greater than is normal. Ever since the results of the first examination of Ingot 64 were published there has been interested speculation concerning the crust on the top of it. The crust appears to be almost as thick as the rim itself, and the observers reported that the rimming action was obscured by a crust of metal, and that there was no visible evolution of gas. The section conveys to the author of the paper the impression that this crust must have grown continuously as the metal rose in the mould, and that its formation might be due, in part at least, to solidification without any assistance from rimming action.

The author discusses the rimming action, and the blow-hole distribution in ingots 9368 and 9369 as indicated by the sulphur prints and macro-etchings.

Discussing the results of detailed chemical analysis, the author points out that all three ingots have this in common: there is a gradual diminution in the percentage of carbon, manganese, sulphur and phosphorus as one traverses the rim from the outside surface towards the junction zone. There is also in each ingot a discontinuity in the percentage of these elements at the junction zone, but whereas in the case of Ingots 64 and 9368 there is a sharp rise in the percentage of the varied elements at the junction which is not maintained at its peak throughout the core, in the case of Ingot 9369, the moderate rise which occurs represents a figure only slightly higher than the average percentage in the core itself. This suggests that, because of relative freedom from blow-holes in the junction zone or for some other reason, there has been no excessive build-up of impurity where the rim ceased to form.

In discussing the results of the investigation the author argues that it is justifiable to regard Ingot 9369 as a normal ingot, and Ingot 64 and 9368 as abnormal. He points out that when Ingot 64 was made the converters were working only one shift of 8 hours per day; the mixer metal contained only 0·34% of silicon and would almost certainly be cold; the blow was heavily scrapped before ever the converter was turned up for blowing; the time intervals during which the converter was not blowing, after the metal addition, make up an aggregate of unusually long duration and therefore it can be taken as certain that this ingot is the product of a cold blow, and that the factor of temperature bulked largely in the results obtained. Confirmation of this is obtained from the reports of the observers.

Ingots 9368 and 9369 were made from separate blows in more nearly normal works conditions. Ingot 9369, correctly described by the observers as a perfect example of a rimming ingot, was obtained without any difficulty, but great difficulty was experienced in attempting to duplicate Ingot 64. Ingot 9368 is, in some respects, intermediate between the perfect example (9369) and the very abnormal Ingot 64, but it is not so clear that the abnormality is due to temperature causes.

The author discusses the variation in the rimming action, and points out that excessive oxygen is not necessary. The conditions for vigorous mould effervescence are correct temperature, low manganese, and correct oxygen.

Reviewing the behaviour of the steel in the mould, he shows that a greater degree of homogeneity was obtained throughout the core section in the ingot in which the rimming was sufficiently active.

The author's conclusions are:—

(1) The temperature, state of oxidation and manganese content are the controlling factors in the rimming action.

(2) Vigorous effervescence reduces the tendency to excessive local segregation and assists in producing uniformity as regards both composition and freedom from non-metallic impurity.

(3) Ingot structures may be obtained in unkilled steel which simulate in a remarkable degree the final structure of a properly rimmed ingot, even when the conditions are not favourable to correct rimming action.

Mr. Mitchell is to be congratulated on having done a good deal towards clearing up the mist that many people found themselves in when they were considering Ingots 63 and 64. His conclusions regarding what is required, from a practical point of view, to make good rimming ingots, would seem to us to be such as will find general acceptance in the industry.

Paper No. 14. In this paper Mr. Mitchell studies four low-carbon basic Bessemer ingots of British manufacture, all cast from the same blow. As far as possible the conditions of manufacture and examination were kept constant, in order that the effect of mould size might be studied. The study covers four ingots, whose weights were 4·35 tons, 3·1 tons, 2·35 tons and 1·3 tons; they varied in length from 66—70 in.

The ingots were sectioned, sulphur-printed, macro-etched and analytically explored, the procedure adopted in making and examining them being directed to elucidating the effect of mould size on the rimming process and product. With this object, to each ingot aluminium was added at the rate of 1 oz. per ton of steel, and as a result perhaps only the 2-ton ingot can be regarded as normal. The author shows that the rim thickness varies with the ingot size, that the rim increases gradually in thickness from the top to the bottom in each case, and that the relative amount of rim to core decreases with increasing ingot size.

He discusses in detail the chemical heterogeneity with particular reference to (*a*) horizontal variations in composition at different heights; (*b*) vertical variations; and (*c*) variations related to ingot size. The conclusions the author draws from his examination is that moulds of different sizes require metal of varying degrees of effervescence to produce ingots of the same character, and that, in general, where extreme purity of the rim is desirable for practical purposes, this can be better attained in larger than in small ingots, provided that the initial material has a sufficiently vigorous effervescence to be controlled by aluminium.

Any ingot size, within the limits studied, is permissible provided that the rimming characteristics of the metal are

modified to suit the particular size of ingot selected, although it is probable that in day-to-day practice it would be easier to secure a better mill yield from smaller-sized ingots, other conditions being the same.

Such an experiment as this must be considered a valuable record, and will be used as a yardstick by other operators. It must have happened to many makers of rimming steel to have moulds of varied sizes in the same cast, and to note the difference in the behaviour of the steel in each size. The role played by mould size will be better understood in future.

One of the most interesting features of this paper seems almost a digression (at least from the subject of influence of mould size). The author states his views as to what happens in the mould during the filling and solidification of a rimmed-steel ingot. He discusses the effect of mechanical turbulence, effervescence, and falling temperature. He believes, contrary to some opinion, that a chilled skin is formed in steels of all compositions. The thickness of it depends on several factors, but its growth will end when carbon-monoxide evolution starts, which will be when the concentration of oxide on the cooling face is sufficient to upset equilibrium and start the gas-evolution reaction. He suggests that the rim is the result of two distinct processes :

(*a*) Solidification of some liquor of average composition *in situ*, due to local temperature, i.e., normal crystallisation of material from mother liquor ; and

(*b*) The deposition of iron particles of high relative purity which are the product of the iron-oxide/carbon reaction.

This latter conception is most interesting. The author draws the analogy of iron " coming to nature " in the puddling process. He suggests that the particles, though very small, will serve as nuclei and carry down with them considerably more iron than is represented by their own initial weight. He conceives that the rim will be made up of relatively impure crystals, which have solidified in the usual way, welded into a continuous crystal mass with the postulated precipitated grains or crystals of very pure iron.

Paper No. 13. This paper, by Dr. Binnie, records the manufacture and detailed examination of a rimmed-steel ingot. The ingot was made by the basic open-hearth process, and had a pit analysis of 0·08% of carbon and 0·30% of manganese. The ingot was sectioned on its vertical axis, polished and sulphur-printed. Drillings from the standard positions were analysed. A detailed examination of the zones which were particularly rich in sulphur showed the presence of numerous pale yellow inclusions which were probably free iron sulphide.

A particularly interesting feature of the paper is the section devoted to the consideration of the core of the ingot. Here the author first shows that in this ingot the general analysis of the core showed a loss in carbon from the pit figure of 0·08%, the average core carbon being 0·045% and the average rim carbon 0·03%, with the manganese content fairly steady throughout at 0·29—0·30%. He then refers to Hultgren and Phragmén's work, which states that with liquid steel with higher carbon than balanced composition the carbon would increase in the liquid metal during freezing under gas evolution ; for metal of lower carbon content than the balanced composition the opposite held, i.e., the carbon in the liquid metal during freezing would decrease. Hultgren and Phragmén fixed the carbon content of the balanced composition at about 0·06%.

The author develops this hypothesis mathematically to include the influence of manganese and pressure on the carbon and oxygen values of the balanced composition, and shows that with increasing manganese content, as well as with increasing pressure, the carbon content of the balanced composition is progressively increased.

The author re-examines the existing data concerning Ingots No. 24, 59, 61, 62, 63, 64, 65 and 34/8940, and concludes that they would appear to support Hultgren and Phragmén's balanced-composition hypothesis. To establish a complete experimental verification of the hypothesis the carbon content, and also the oxygen content, of the liquid metal in the ladle would require to be known accurately. This point is also made by Dr. Swinden in paper No. 15.

In conclusion, Dr. Binnie points out that in the published examinations of rimmed steel ingots the pit carbon analysis recorded was, in many instances, obviously too low, and investigators of rimming steel ingots should, in future, pay particular attention to this point.

Paper No. 15. This paper deals with a basic open-hearth steel ingot from a cast with a pit sample carbon content of 0·047%, and containing only 0·10% of manganese. The paper represents a continuation of the work reported on in Section III of the Ninth Report, with particular reference to the Hultgren and Phragmén hypothesis on rimming action. In the Ninth Report Dr. Swinden showed that the rimming steel of cast 34/8940 conformed to the hypothesis for a steel having a carbon content higher than the balanced composition. What was then left without complete data, however, was whether steel having a carbon content lower than the balanced composition would also conform and give rise to the reverse curve.

The result of the very careful detailed examination of this ingot is to provide excellent verification of the hypothesis. The results also show that the actual values for carbon and oxygen representing the balanced composition, namely, 0·06% of carbon and 0·04% of oxygen appear to be substantially correct.

Paper No. 16. This note deals with the effect of reheating for 46 hours at about 1,300° C. a 7¼-in. square bloom section of 0·09% carbon rimming steel.

There is a very slight diffusion of carbon from the core to the rim zone. There is no apparent migration of sulphur from the core to the rim ; in fact, the rim-core demarcation is even more sharply defined on the sulphur print after treatment than before.

Some interesting observations are made on the changes in constitution and distribution of the inclusions, particularly within the core zone.

These five papers, as a group, will be readily accepted as a valuable series of stepping-stones on the path to knowledge of rimming steels. They are typical of the contributions to the common good that are so often made by the Committee. A brief glance at the history of the Committee's grapple with the problems presented by rimming steels shows how their efforts have been unerringly directed at the vital points—pure research and works research side by side. It will be gladly conceded that the scientific work of Hultgren and Phragmén, in Sweden, has been extremely valuable and helpful, but the speed with which it has been followed up must redound to the credit of the scientific workers in Britain's steel industry. Mr. Mitchell's work, following upon all the practical work recorded in the Ninth Report, leaves no room for doubt that the works angle of the problem is receiving, in consideration, no less than its due. The members of the Committee may well feel satisfied with their progress towards an understanding of the phenomena connected with the production of rimming steels.

The Nickel Bulletin

THE November issue of *The Nickel Bulletin* contains an unusual amount of tabulated data of American origin on various subjects, including :—Scrap Identification, Resistance Materials Characteristics, Properties of Electrical Contacts, Aeronautical Steel Specifications, Creep Properties of Nickel-Chromium Heat-Resisting Steel, and Tensile Strength of Stainless Steel Welds at Low Temperatures.

Copies may be obtained free of charge from The Bureau of Information on Nickel, the Mond Nickel Company, Ltd., Grosvenor House, Park Lane, London, W. 1. Individuals are asked to state the name of their firm, or otherwise indicate the nature of their interest.

Nitrogen as an Alloying Element in Cr-Ni-Steels

By D. W. Rudorff, A.Am.I.E.E., M.Inst.F.

It has long been realised that nitrogen has a considerable influence on certain steels. The results of investigations carried out in a number of countries, especially with high-chromium steels, confirm this influence, and although opinions differ on the value of this element as a constituent in steel, it is noteworthy that Germany has developed a number of stainless and heat-resisting steels in which much of the nickel content is replaced by nitrogen. This development is briefly reviewed.

SYSTEMATIC research conducted over a number of years into the possible use of nitrogen as an alloying element in steels with high-chromium content has finally culminated in the development in Germany of a number of commercial stainless and heat-resisting steels in which a considerable part of the nickel content is replaced by nitrogen.

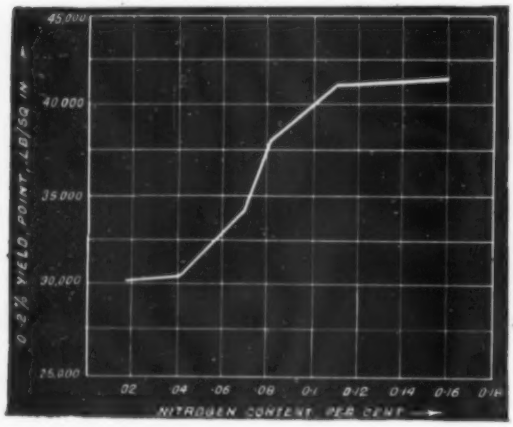


Fig. 1.—Influence of the N_2 content upon the yield point of an 18% Cr—8% Ni steel.

Investigations into the alloying properties of nitrogen have, of course, by no means been confined to Germany. On the contrary, as far back as in 1927, F. Adcock[1] had drawn attention to the effects of nitrogen on chromium and some chromium alloys. In Adcock's experiments samples of iron, chromium and iron-chromium alloys were treated with nitrogen for 30—50 mins. by passing the gas over the surface of the metal in liquid state, nitrogen contents up to 3·9% being readily obtained. Chromium-iron alloys in solid state were also found to absorb nitrogen if annealed at moderate and high temperatures under conditions which permitted the access of nitrogen. Investigating test-pieces of 17·5 and 24·5% Cr with low carbon percentage, which are by nature ferritic, Adcock further found that the pieces contained islands of fine-grained martensite-like structure, or of fine-lamellar and pearlite-like appearance. An explanation of this phenomenon was advanced by V. N. Krivobok[2] in 1934-35. He stated that this fine-grained structure is due to the fact that, like carbon, nitrogen acts to extend the existence of the γ-phase into regions of higher chromium content. In 1933 important practical progress was made by R. Franks[3] by ascertaining that nitrogen leads to grain refinement in cast ferritic-chromium steels, and in wrought steels causes a considerable diminution of grain growth after heating at high temperature; while an austenitic 18% Cr–8% Ni steel exhibited an increase in its yield point. But he also claimed nitrogen to have an important detrimental effect upon the properties of wrought Cr–Ni steels in so far as the material exhibits decreased stability at elevated temperatures. According to Franks, high-nitrogen steels held for relatively long periods at temperatures between 600°—900° C. suffer a greater decrease in toughness than a metal having the same percentage of carbon with normal nitrogen. High-nitrogen steels are said to be subject to intergranular attack, and in this respect offer no improvement over usual types of material.

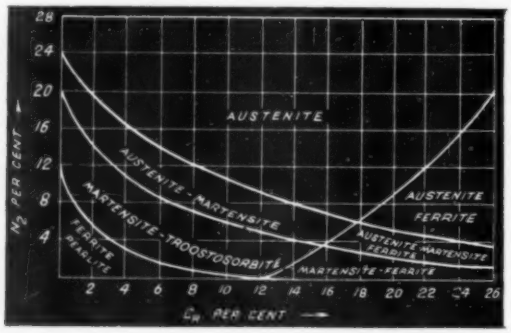


Fig. 2.—Phase diagram of Cr-Ni steels.

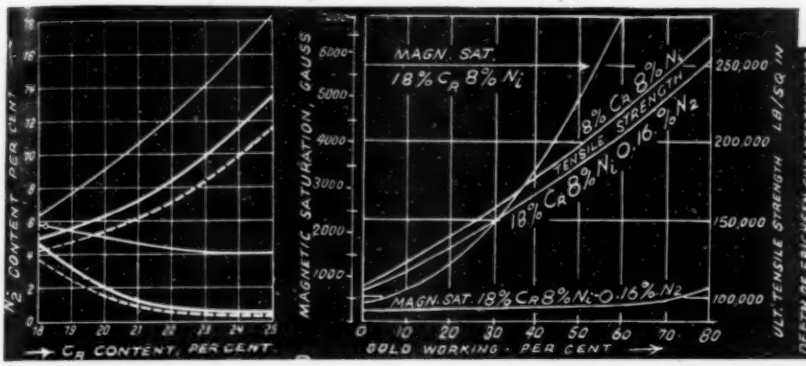
While in Adcock's experiments nitrogen was imparted in gaseous state, Franks employed the more practical method of adding it in the form of high-nitrogen ferro-chromium, having the appropriate chromium/nitrogen ratio. As Franks points out, this should not be added to excessively hot steel, as this would tend to cause decomposition of the nitrides and liberation of gaseous nitrogen. The solubility of nitrogen in chromium steels has been studied by M. R Brick and J. A. Creery,[4] and also by T. Kootz.[5] Since the N 2 content of chromium-alloyed steel can amount to only 1/75—1/100 of the Cr content, nitrogen alloying is limited to steels with more than 10% Cr or Mn content. A ferro alloy containing nitrogen in the correct proportion will have to contain 60—70% Cr and 0·7—0·9% N 2: but it is, of course, also possible to use a ferro-chrome of 50—70% Cr, which may be enriched by means of diffusion to as much as 12% nitrogen.

In a recent investigation of the practical possibilities of nitrogen-alloyed austenitic Mn–Cr steels containing 17—18% Mn, G. Riedrich[6] was able to ascertain that the addition of nitrogen leads to an increase in the yield point, at the same time improving austenite stability. An examination by R. Scherer[7] of the influence of the nitrogen content upon the deep-drawing qualities of an 18% Cr–8% Ni material revealed a highly beneficial influence of nitrogen in this respect; and this worker also found that in high-alloyed Cr–Ni steels 3—4% of the nickel content can be replaced by 0·1% nitrogen. This possibility of substitution was confirmed by W. Torfaute and H. Schottky,[8] who conducted a number of tests on a steel of approximately 23% Cr. According to F. Rapatz,[9] chromium-manganese steels alloyed with Ta + Nb, which are known to be liable to intercrystalline corrosion, can be improved by a

1 F. Adcock. "The Effect of Nirtogen on Chromium and Some Iron-Chromium Alloys, *Journal Iron and Steel Inst.*, vol. 114, 1926, p. 117.
2 V. N. Krivobok. "Alloys of Iron and Chromium." *Trans. Am. Soc. Met.*, vol. 23, 1935, p. 1.
3 R. Franks. "Chromium Steels of High Nitrogen Content." *Trans. Am. Soc. Met.*, vol. 23, 1935, p. 968.
4 Am. Inst. Min. Met. Engrs., Technical Publication No. 1165.
5 T. Kootz. *Ar. E. H. Wesen*, vol. 15, 1941-42, p. 77.
6 G. Riedrich. "Non-magnetic Construction Steels with 17—18% Manganese." *Stahl und Eisen*, vol. 60, 1940, p. 815.
7 R. Scherer. *Chem. Fabrik*, vol. 13, 1940, p. 373.
8 W. Torfaute and H. Schottky. *Ar. E. H. Wesen*, vol. 14, 1940-41, p. 71.

addition of nitrogen. The latter serves to decrease the solubility of the Ta + Nb carbides. A typical analysis of such an improved material is: 0·15% C, 1·01% Si, 7·72% Mn, 22·44% Cr, 1·24% Ni, 0·172% N_2, and 1·18% Nb + Ta.

A most important report on the effects of nitrogen upon the properties of austenitic and austenitic-ferritic chrome-nickel steels has recently been rendered by R. Scherer, G. Riedrich and H. Kessner.[10] The results of their investigations into the influence of nitrogen upon the 0·2% yield point of an austenitic 18% Cr–8% Ni steel are charted in Fig. 1. Here, a steel with an "accidental" nitrogen content of 0·015% N_2 is seen to possess a yield point of 30,390 lb. per sq. in. Practically the same value is recorded for the piece containing 0·04% N_2. However, an increase in the nitrogen content to 0·07% is seen to be accompanied by a rise in the yield point to 34,365 lb. per sq. in., and for a nitrogen content of 0·11%, a 0·2% yield point of 41,300 lb. per sq. in. is charted. Larger nitrogen contents are seen to be of little additive influence. In order to obtain the highest possible yield point a 18% Cr–8% Ni steel should therefore contain from 0·1—0·12% N_2.



— Austenite-ferrite without N_2.
— Austenite-ferrite with *ca.* 0·15% N_2.
--- Austenite-ferrite with *ca.* 0·25% N_2.

Fig. 3.—Influence of nitrogen upon location of the austenitic-ferritic zone of Cr-Ni steels.

MAGN. SAT.
18% Cr 8% Ni
18% Cr 8% Ni 0.16% N2
MAGN. SAT. 18% Cr 8% Ni 0.18% N2
MAGNETIC SATURATION, GAUSS
TENSILE STRENGTH LB/SQ IN
COLD WORKING - PER CENT

Fig. 4.—Magnetic saturation and tensile strength versus percentage of cold working of 18% Cr—8% Ni steel with and without nitrogen.

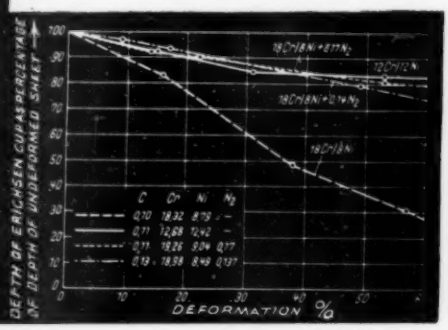


Fig. 5.—Results of wedge-drawing tests for testing deep drawing properties of 18% Cr—8% Ni steels with and without nitrogen, and of 12% Cr—12% Ni steel.

TABLE I.

YIELD POINT (0·2% STRAIN) OF AUSTENITIC, AUSTENITIC-FERRITIC, AND FERRITIC AUSTENITIC CR–NI STEELS, AUSTENITIC MN–CR STEELS, AND AUSTENITIC CRMN STEELS WITH AND WITHOUT NITROGEN ADDITIONS, WATER-QUENCHED FROM 1,050C°

Steel No.	C. %	Si, %	Mn, %	Cr, %	Ni, %	N_2, %	Yield Point, Lb./sq.in.	Structure.
1	0·08	0·31	0·30	17·57	8·32	—	30,390	100% Aust.
2	0·11	0·48	0·42	18·03	8·61	0·13	41,460	100% "
3	0·10	0·37	0·48	17·68	8·52	0·17	43,030	100% "
4	0·10	0·53	0·55	25·44	8·45	—	61,910	60% Aust. 40% Ferr.
5	0·13	0·54	0·68	25·62	4·92	0·14	74,830	60% " 40% "
6	0·11	0·52	0·48	25·96	3·49	0·29	76,970	60% " 40% "
7	0·12	0·68	0·75	26·26	3·52	—	68,590	20% " 80% "
8	0·14	0·73	0·61	25·36	1·41	0·15	65,600	20% " 80% "
9	0·34	0·32	17·93	5·81	1·77	—	34,900	100% Aust.
10	0·32	0·44	18·03	6·72	2·04	0·09	50,980	100% "
11	0·15	0·82	7·78	14·44	1·52	—	39,350	100% "
12	0·16	0·68	7·93	14·96	1·42	0·11	51,400	100% "

Similar considerations apply to austenitic-ferritic Cr–Ni steels. Thus a steel of this kind containing about 60% austenite and 40% ferrite, with an analysis as that given for steel No. 4 in Table I, has a 0·2% yield point value of 61,900 lb. per sq. in. That this value is considerably above that encountered with a purely austenitic 18% Cr–8% Ni steel is explained by the ferritic contents.[11] But for the 60% austenitic–40% ferrite steels No. 5 (Table I), containing 0·14% N_2, a yield point of 74,800 lb. per sq. in. is recorded. That larger nitrogen contents do not effect further improvements in the yield point of austenitic-ferritic Cr–Ni steels is proven by the fact that the Cr–Ni steel No. 6, with 0·29% N_2 and an austenite/ferrite ratio of 60/40, exhibits an only slightly higher yield point value than steel No. 5.

In austenitic-ferritic Cr–Ni steels with less than 30% austenite content no improvement in the yield point is obtained by nitrogen additions. This is evidenced by the case of steel No. 8, containing 20% austenite and 80% ferrite, the yield point of which approximates to that recorded for steel No. 7, the latter also being a 20% austenite–80% ferrite Cr–Ni steel, but containing no measurable nitrogen content. It is interesting to note that the other mechanical properties are not influenced by nitrogen additions. The test results obtained with the steels No. 11 and No. 12, given in Table I, serve as a good example of the improvement in yield point obtainable by nitrogen additions to the aforementioned Cr–Mn steels.

Influence of the Nitrogen Content upon the Microstructure

It was already mentioned that (similar to the action of carbon) nitrogen extends the γ-phase of high-chromium steels to higher chromium percentages. This effect can also be observed with high-alloyed Cr–Ni steels. In this case the border lines of the austenite-ferrite range are shifted towards lower nickel contents. Referring to Fig. 2, an 18% Cr steel with approximately 7% Ni is seen to lie closely above the austenite-ferrite and austenite-ferrite-martensite ranges. In order to be purely austenitic a 20% Cr steel must, therefore, contain at least 9·5% Ni; while the corresponding minimum requirements of a 25% Cr steel are given by an 18% Ni content. For the purpose of achieving an austenitic-ferritic 20% Cr steel, it must be made to contain at least 5·5% Ni; while the nickel contents of a 25% Cr steel must not be less than 4·0%.

Fig. 3 shows the austenitic-ferritic range of Cr–Ni steels investigated by R. Scherer, G. Riedrich and H. Kessner,[10] which steels contain approximately 0·1% C and N_2 additions of *ca.* 0·15% and 0·25% respectively. It will be noted that the 18-20% Cr corner of the austenite-ferrite range, referring to steels with 0·25% N_2, is shown in weaker broken lines. This is done in order to point out that it is rather difficult to realise 20% Cr steels with a nitrogen content of about 0·25%. The diagram clearly shows that nitrogen additions serve to shift the border lines of the austenite-ferrite range towards regions of lower nickel percentage. This can be used as an indication as to how much nickel can be replaced by nitrogen. According to the diagram (Fig. 3), an 18% Cr steel with 0·15% N_2 and 5·5% Ni lies closely above the austenite-ferrite and austenite-martensite-ferrite ranges; while a 20% Cr steel with the same nitrogen percentage requires only 6·5% nickel in order to be purely austenitic; and with a 25% Cr steel this requirement falls from 18—14%. With a

[9] F. Rapatz. "Possible Uses of Corrosion and Heat-Resistant Steels with Nitrogen Additions," *Stahl und Eisen*, vol. 61, 1941, p. 1,073.
[10] R. Scherer, G. Riedrich and H. Kessner. "Effect of Nitrogen upon the Properties of Austenitic and Austenitic-Ferritic Cr–Ni Steels," *Stahl und Eisen*, vol, 62, 1942, p. 347.
[11] R. Scherer, G. Riedrich and G. Huch. *Ar. E. H. Wesen*, vol. 13, 1939-40, p. 53.

0·25% N_2 content, purely austenitic structure is achieved with 20% Cr and 5·5% Ni, and with 25% Cr and with 12% Ni. If 0·15% nitrogen is added, austenitic-ferritic structure is still obtained with 20% Cr–2·5% Ni and with 25% Cr–1·0% Ni steels. It can be concluded that from the structural viewpoint, according to the height of Cr percentage, 2—4% Ni can be replaced by *ca.* 0·15%, while 0·25% N_2 will replace from 2·5-6% nickel.

Where a non-rusting and acid-resisting material is called for, austenitic-ferritic Cr–Ni steels can be used instead of the austenitic variety, provided the ferrite contents do not exceed 20%, since the toughness of such austenitic-ferritic materials is almost as good as that of the austenitic material. It is well known that austenitic-ferritic Cr–Ni steels with 10—20% ferrite show greater resistance to carbide precipitation than the purely austenitic material, and steels of this kind can be made stable by proper heat-treatment.[11] This applies also to austenitic-ferritic Cr–Ni steels with nitrogen. Scherer, Riedrich and Kessner[10] found that Cr–Ni–N_2 steels with up to 30% ferrite still show satisfactory mechanical properties. Thus, for instance, a steel with 0·1% C, 20·7% Cr, 2·32% Ni, and 0·144% N_2 with 30% ferrite, has an elongation of 49% and a notched-bar impact strength of about 144·6 ft.-lb. A steel containing 0·13% C, 24·48% Cr, 7·10% Ni, and 0·134% N_2 with 20% ferrite registered an elongation of about 34% and an impact strength of 130·1 ft.-lb, whilst a material having 0·11% C, 25·38% Cr, 4·66% Ni, and 0·253% N_2 with 30% ferrite possesses an elongation of 30% and an impact strength of 115·7 ft.-lb.

Thus, where a stainless material is required, austenitic and austenitic-ferritic Cr–Ni–N_2 steels with *ca.* 0·1% C, 20—25% Cr, 4—5·5% Ni and *ca.* 0·2% N_2 can be used. These steels are easily worked and possess a high degree of toughness and also good chemical and intercrystalline stability.

Influence of Nitrogen Additions Upon the Cold-working Properties of 18% Cr—8% Ni Steels

Scherer, Riedrich and Kessner[10] point out that nitrogen increases the austenite stability of both austenitic Cr–Ni and austenitic Mn–Cr steels. It is known that the austenitic 18% Cr–8% Ni material does not remain austenitic after cold working, but becomes increasingly martensitic according to the degree it is cold worked. This change is accompanied by an increase in magnetic saturation from its original value of *ca.* 500 gauss.[12] After 20% cold working, the 18% Cr–8% Ni material shows a magnetic saturation of about 1,300 gauss, and after 60% cold working a value of 7,000 gauss. In contrast to this a material containing 18% Cr, 8% Ni, and 0·15% N_2 does not exhibit any marked increase in magnetic saturation with cold working. This is illustrated by the test data charted in Fig. 4, and it follows that cold working of this material does not lead to a transformation of austenite into martensite, since the nitrogen content has increased the stability of the austenite. The fact that the tensile strength curves of the steel with, and of that without, nitrogen run almost parallel can be taken to indicate that the austenite-stabilising action of the nitrogen does in no way impair the occurrence of work-hardness; and this applies also to austenitic Cr–Mn steels.[9] These steels, therefore, represent a non-magnetic material with tensile strengths ranging as high as 227,000—284,000 lb. per sq. in.

The austenite-stabilising action of the nitrogen content during cold working is of particularly beneficial influence upon the deep-drawing qualities of these materials. For judging deep-drawing properties, the Kayseler wedge-drawing test[13] is said to have proven especially useful and reliable. Fig. 5 shows the results of the deep-drawing tests conducted with the 18% Cr–8% Ni steels and a 12% Cr–12% Ni steel, and also with two steels of similar composition but containing approximately 0·15% N_2. As the graph shows, the deep-drawing properties of these steels are improved by the addition of nitrogen to a point where this material possesses equally good drawing qualities as the 12% Cr–12% Ni material. These favourable findings are said to have been fully confirmed by manufacturing experiences.

The Influence of Elevated Temperature

In order to explore the applicability of austenitic and austenitic-ferritic Cr–Ni–N_2 steels to high-temperature work, a special set of tests was carried out by Scherer, Riedrich and Kessner[10] so as to ascertain the tendency of these steels to embrittlement after exposure to elevated temperature. As W. Torfaute and H. Schottky[8] have shown, a 0·06% C, 22·5% Cr, 4·13% Ni chrome-nickel steel with 0·29% N_2 exhibits greatest loss in toughness after long time exposure to 500° C.; while the 18% Cr–8% Ni material shows the greatest decrease in impact strength after long time heating at 800° C.[14]. Scherer and his associates, however, emphasise that this difference in behaviour is not due to the nitrogen content, and they claim that this contention has been confirmed by long time heating tests at 200°—900° C., made with Cr–Ni–N_2 steels containing 20% and 25% Cr, respectively. The actual results of these tests are charted in Figs. 6 and 7. Here it can be seen that the embrittlement of the fully austenitic Cr–Ni–N_2 steels, after 100 hours heating at 200° –900° C., is greatest at 800° C. It can, therefore, be assumed that purely austenitic Cr–Ni–N_2 steels possess embrittlement characteristics similar to austenitic Cr–Ni steels without nitrogen. Further tests will, however, have to be carried out in order to clarify the situation.

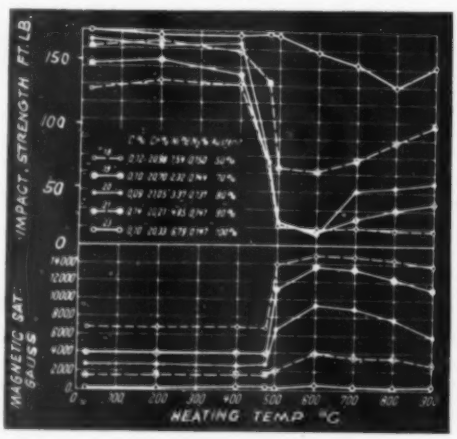


Fig. 6.—Impact strength and magnetic saturation after holding at various temperatures for 100 hours, after water-quench, from 1,100° C. of steels with 20% Cr, 0.15% N_2 and 1.5—7.0% Ni.

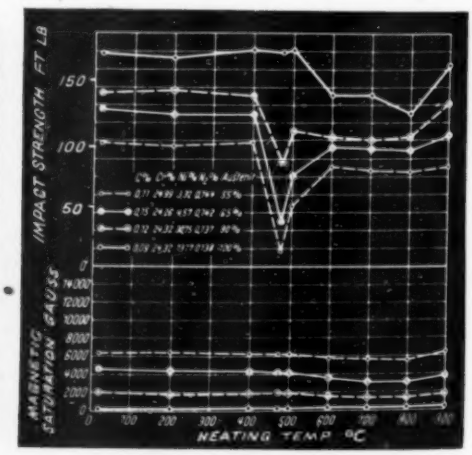


Fig. 7.—Impact strength and magnetic saturation after holding at various temperatures for 100 hours, after water-quench, from 1,100° C. of steel with 25% Cr, 0.15% N_2 and 3—13% Ni.

12 P. Schafmeister and A. Gotta, *Ar. E. H. Wesen*, vol. 5, 1931-32, p. 427.

13 H. Kayseler *et al*, *Stahl und Eisen*, vol. 54, 1934, p. 993. H. Kayseler and W. Puengel, *Mitt. Kohle und Eisenf.*, vol. 2, 1939, p. 141. A description of this test method is given by J. D. Jevons, "Metallurgy of Deep Drawing and Pressing" (Chapman and Hall, 1941), p. 521.

14 B. Strauss, H. Schottky and J. Hinnueber, *Z. an allg. Chemie*, vol. 188, 1930, p. 309; cf. *Stahl und Eisen*, vol. 50, 1930, p. 1,473.

Figs. 6 and 7 show that the embrittlement tendency of austenitic-ferritic Cr–Ni–N_2 steels is quite different from that observed with the purely austenitic steels of this class. After heating at temperatures above 400° C., these austenitic-ferritic steels are seen to exhibit a sharp decrease in impact strength. As Fig. 7 shows, the three austenitic-ferritic Cr–Ni–N_2 steels with approximately 25% Cr content show a maximum loss in impact strength after long time heating at 475° C., and this tendency is seen to increase with the ferrite percentage. The fact that the tendency to embrittlement of these steels is more marked than that experienced with 20% Cr steels can be explained by the deleterious influence exerted by the increased chromium content upon the 400°—500° C. brittleness.

A comparison of the magnetic saturation curves given in Fig. 6 and 7 shows that the 25% Cr steels do not exhibit the increase in magnetic saturation experienced with the austenitic-ferritic 20% Cr steels after long time heating at 500° C., which increase is due to a partial transformation of austenite into martensite. Such a transformation is therefore absent in the case of the 25% Cr steels. The superior impact strength values given for the 100% austenitic 20% and 25% Cr–Ni–N_2 steels indicate that only purely austenitic steels of this type should be employed with temperatures exceeding 300° C.

Heat-resisting Cr—Ni—N_2 Steels

That partial replacement of the nickel content by nitrogen in heat-resisting Cr–Ni steels does not diminish their resistance to scaling is evidenced by the test results given in the subjoined Table II. It should be noted that the steels listed are of the purely austenitic variety—that is to say, the remaining nickel content was kept large enough to maintain a purely austenitic structure. Referring to the loss-in-weight data listed, it will be seen that the scaling resistance of the steel containing 21·5% Cr, 12·5% Ni, 1·5% Si, and 0·2% N_2 is even superior to that of the well-known 25% Cr, 20% Ni, 2% Si material. With regard to impact strength, the superiority is still more pronounced, the relative losses in impact strength at 800° C. being 50% and 85%, respectively.

Scherer and his associates summarise the results of their investigations as follows :—

(1) Additions of 0·1—0·12% N_2 to austenitic and to austenitic-ferritic Cr–Ni steels with at least 30% austenite content serve to raise the yield point by approximately 11,360 lb. per sq. in.

(2) According to chromium percentage, 2—4% Ni can be replaced by 0·1% nitrogen, and 2·5—6% Ni by 0·25% N_2.

(3) Additions of nitrogen increase austenite stability.

(4) The presence of nitrogen does not increase the tendency to embrittlement at elevated temperature.

(5) Where corrosion resistance is the main consideration, austenitic and austenitic-ferritic steels with approximately 0·1% C, 21—25% Cr, 4—5·5% Ni, and 0·22% N_2 are recommended.

(6) In the range of heat-resisting steels, the 0·15% C, 25% Cr, 20% Ni, 2% Si steel, heretofore employed for temperatures up to 1,200° C., can be replaced by a material containing *ca.* 0·15% C, 22% Cr, 13% Ni, 1·4% Si, and 0·2% N_2.

TABLE II.
SCALING RESISTANCE OF AUSTENITIC CR–NI STEELS WITH AND WITHOUT N_2.

C, %.	Si, %.	Cr, %.	Ni, %.	N_2, %.	Loss in Impact Strength after holding at 800° C. for 100 hours, %.	Weight-loss by Scaling in Gramme/sq. m. hour at				
						1,000°C.	1,050°C.	1,100°C.	1,150°C.	1,200°C.
0·15	0·56	25·7	19·25	—	45	0·85	1·20	1·50	2·05	2·70
0·16	2·64	24·93	20·42	—	85	0·75	0·87	1·19	1·60	2·20
0·10	0·52	24·62	12·62	0·179	45	0·65	0·75	0·98	1·33	1·80
0·11	1·78	24·80	12·94	0·216	70	0·50	0·60	0·78	1·10	1·50
0·10	1·64	21·38	12·64	0·173	50	0·49	0·50	0·65	1·10	1·55

Electrolytical Precipitation of Manganese from Solutions of Manganese Chlorides.

EXPERIMENTS to precipitate manganese out of pure electrolytes of manganese chlorides have supported results obtained by other workers, and gave no satisfactory results because of the rapid decay of the electrolytes. Thanheiser and Hubold* found, however, that when adding ammonium chlorides best results could be obtained in the case of high concentration of manganese in the electrolyte (3 lb. to 5 lb./cub. ft. of manganese and 10 lb./cub. ft. of ammonium chlorides). Electrolytes with high contents of ammonium chloride gave comparatively satisfactory precipitations even with low concentrations of manganese chlorides, while with high manganese chloride and low contents of ammonium chloride no useful results could be obtained in any case.

The stability of the electrolyte also depends to a high degree on the contents of ammonium chloride. It grows with increasing contents. The current densities used in the experiments ranged from 0·16 to 1·3 A./sq. in., the best ampere efficiencies being obtained at a current density of about 0·65 A./sq. in. During the electrolysis the pH figure for the electrolyte changed to the acid side and could be kept in the required range only by continuous addition of ammonia. The formation of precipitate improved with increasing stirring speed, but the excess beyond a certain speed limit brought only very small further improvement.

Even at an increased temperature of the cell of 42° C. precipitates of manganese could be obtained, the ampere efficiencies being somewhat higher than at 20° C. in consequence of the lower cell voltage. High current efficiencies (2·3 A./sq. in.) make possible a good precipitation of the manganese even with higher temperatures (58° C.). Precipitation experiments without using diaphragms resulted in bad manganese coatings and unsatisfactory ampere efficiencies.

By means of a special apparatus developed for conducting the electrolysis, the quantity of the precipitated manganese could be determined at any moment during the experiments. Thus, it could be stated that the uncertainty in reproducing the results of the experiments is mainly due to the fact that the precipitated manganese is lifted from the base material and exposed to attack by the electrolyte. The moment of lifting is indicated by a break of the precipitation curve. It has also been found by long-term experiments that the concentration of manganese in the electrolyte can be lowered to a comparatively high degree without decreasing the quantity of manganese precipitated per unit of time.

The formation of precipitate seems to be of fundamental importance for the precipitation of the manganese. With coarse crystalline layers bad properties of growth could always be observed. The most favourable results were obtained when the manganese was precipitated out in crystalline form.

The cathode material had a smaller influence on the formation of the precipitated manganese than the preliminary treatment of the cathode sheet, the most favourable being polished, and, secondly, slightly etched surfaces of gently matted appearance. The grain size of the cathode material also seems to be of importance to the formation of the manganese precipitate, but further experiments are necessary to obtain numerical data. Also, the process leading to the peeling-off of the deposit of manganese from the cathode sheet could not be satisfactorily explained. Further investigations are therefore necessary to determine what happens inside the manganese deposit during the electrolysis.

* G. Thanheiser and R. Hubold, *Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung in Düsseldorf*, vol. 23, 1.

The Effects of Selenium, Tellurium and Bismuth on the Working Properties of Commercial Copper

*Two investigations have been carried out on the effects of selenium and tellurium, particularly in conjunction with bismuth, on the manufacturing and working properties of copper, with a view to the most efficient use of certain blister coppers, which contain selenium and tellurium, that are available in this country. Some of the information is given from these investigations and an abstract of the authors conclusions as given in the original reports.**

CERTAIN blister coppers containing selenium and tellurium are now available in this country. The most important source is the Ookiep mine (Namaqualand, South Africa). They contain approximately 0·06% of each of these elements, and bismuth of the order of 0·001%. Its possible use, to mix with Rhokana copper having a bismuth content of approximately 0·006%, has been considered, and an investigation is in progress in the laboratories of the British Non-Ferrous Metals Research Association on the effects of selenium and tellurium, particularly in conjunction with bismuth, on the working properties of copper. Part of this investigation is described by Bailey and Hallowes. Another investigation, described by Cook and Parker, is confined to the effect of these elements on deoxidised copper for tube manufacture. Both these papers are published in the November (1942) issue of the *Journal of the Institute of Metals*, and although they do not provide complete information concerning the influence of selenium, tellurium and bismuth on the properties of copper, they can be regarded as a valuable contribution.

The immediate aims of the British Non-Ferrous Metals Research Association were :—

(*a*) To examine the practicability of using mixtures of fire-refined Ookiep and Rhokana coppers for purposes demanding coppers of high qullity.

(*b*) To estimate, as far as possible, the individual and combined influence of selenium, tellurium and bismuth on the mechanical and working properties of copper.

(*c*) To correlate the results of laboratory mechanical tests with behaviour in working operations.

This investigation covers the behaviour in hot-piercing, tube-drawing and hot- and cold-rolling of the two coppers mixed in varying proportions ; in addition, the mechanical properties of the tubes and strips were examined.

The basis materials used in this work were ingots taken from three fire-refined charges of blister copper, consisting respectively of : (1) 100% Ookiep, (2) 100% Rhokana, and (3) a 50 : 50 mixture of Ookiep and Mufulira. Mufulira copper, which has relatively low selenium, tellurium and bismuth contents, was introduced to reduce the amounts of these elements present in some of the charges.

From each of these basis materials, and from mixtures of them, 14 different compositions were used, and the following castings were made :—

(*a*) An oxygen-bearing non-arsenical cake ;

(*b*) a phosphorus-deoxidised non-arsenical cake and tube billet (approximately 0·04% phosphorus) ;

(*c*) a phosphorus-deoxidised arsenical cake and tube billet (approximately 0·03% phosphorus) ;

(*d*) a phosphorus-deoxidised arsenical cake and tube billet (0·06—0·1% phosphorus).

No tough pitch billets were poured. The billets were hot-pierced and cold-drawn to tubes, and the cakes were rolled to strips 0·4 in. thick. The laboratory tests included flattening and doubling over and drifting of the tubes, and tensile and notched bar tests on the strips. Certain properties of the cast billets have also been examined. The annealing atmosphere in manufacturing operations and in laboratory tests was in all cases air.

Reviewing the results, and bearing in mind the aims of the investigation, the authors draw the following conclusions relating to phosphorus-deoxidised coppers :—

(*a*) *Utility of Rhokana-Ookiep Mixtures.*—None of the mixtures made gave material of first quality. Although only one of the non-arsenical coppers failed in hot-piercing, the arsenical mixtures of 0·02—0·03% phosphorus were all difficult to hot-pierce, in which operation 50% of the charges failed completely and only 20% were uncracked. With high phosphorus (0·06—0·1%) only one arsenical billet pierced satisfactorily. On hot-rolling, 33% of the non-arsenical and all the low-phosphorus arsenical coppers showed edge cracking to some extent ; the high-phosphorus arsenical ingots were not so bad in this respect.

Cold-rolling gave no trouble, but all the mixtures tested cracked in the tagging operation in tube manufacture, and some tubes broke in drawing.

In general, therefore, it is clear that Rhokana copper containing 0·006% bismuth, Ookiep copper with 0·06% selenium, and 0·06% tellurium, and any mixture of the two, while perfectly suitable for many purposes, cannot be satisfactorily fabricated by the more severe hot- and cold-working operations which the purer coppers survive.

(*b*) *Effects of Selenium and Tellurium, with High and Low Bismuth, on Mechanical Properties of Copper.*—In the cold-worked condition none of the mixtures gave such good results as coppers of the highest purity in flattening and bending and drifting of tubes, or in notched bar, tensile and reverse-bend tests on rolled strip. In arsenical and non-arsenical mixtures low in phosphorus, elongation and reduction of area values on the strip were all relatively poor, and the addition of high phosphorus (0·06—0·1%) to the arsenical mixtures did not appear to have improved the properties of the few tubes which could be drawn.

The individual effects of selenium and tellurium are largely masked in this work by the greater effects of bismuth, and, to a lesser extent, arsenic and phosphorus. It can be said, however, that selenium and tellurium in amounts up to 0·06% each have no effect on the high-temperature notched-bar tests, but reduce the ductility of copper, particularly in the cold-worked condition. The presence of moderate amounts of these elements may prevent copper from passing working operations which approach the limit of endurance of high-purity metal, but they do not appear to have any disastrous embrittling effect. The permissible limits for these elements will depend on the severity of the working operations involved, but no detailed specifications can be drawn up on the evidence so far available.

(*c*) *Manufacturing and Laboratory Tests.*—From the point of view of further work on the effects of individual

*G. L. Bailey and A. P. C. Hallowes, *J. Inst. Metals*, 1942, **68**, 347. Dr. M. Cook and Dr. G. Parker, *J. Inst. Metals*, 1942, **68**, 369.

impurities in copper considerable attention has been paid to the possibility of deducing behaviour in manufacture from laboratory tests. Detailed comparisons of the results permit the authors to make the following tentative conclusions :—

(1) No completely satisfactory correlation between the results of laboratory tests and the behaviour in hot-piercing of billets has been obtained. There is an indication that the tendency to break of notched-bar specimens tested at 900° C., and the results of hot-bend tests on specimens cut from cast billets, provided some guide to hot-working properties. Further work is necessary, however, before any definite conclusions on this point can be drawn.

(2) The poor behaviour in cold "tagging" of all the tubes made, accompanied reduced ductility of the cold-worked strips, particularly shown by reduction of area measurements on transverse test-pieces, and by reverse-bend tests on thin strip. Similar lack of ductility is shown by drifting and by flattening and bending tests on the cold-drawn tubes, in which tests all the mixtures were inferior to the higher purity tubes.

(3) Tests on annealed materials show close correlation between drifting and flattening and bending of tubes on the one hand and reduction of area in tensile tests on strip on the other. In annealed materials with about 0·001% bismuth, the selenium and tellurium, 0·025—0·05% each, however, reductions of area are below those for Roan copper.

(*d*) *General Conclusion on the Effects of Selenium and Tellurium.*—While effects of selenium and tellurium on copper and permissible limits for these impurities cannot be close-gauged from this work, owing to the greater effects of other elements present, it is clear that in amounts of the order of 0·02—0·03%, and more, these elements reduce the ductility of copper in operations at atmospheric temperature. It should be emphasised that the effects are not so great as to make copper unsuitable for less-severe operations, and the presence of these elements does not render copper unsatisfactory for all applications. At the same time small amounts of these elements may determine the suitability or otherwise of pure copper for drastic treatment.

The effects of selenium and tellurium on hot-working properties appear to be slight in high-temperature notched-bar tests, but their influence on the hot-piercing behaviour of billets may be considerable.

Effect of Selenium, Tellurium and Bismuth on Deoxidised Copper for Tube Manufacture

The work described in this report by Cook and Parker is not a systematic investigation into the effect of these elements on the properties of copper, but is confined to their effect on the fabricating qualities of the metal, particularly in processing tubes by hot-piercing and cold-drawing. Some results are included of tensile and bend tests which have been carried out on samples taken from finished tubes.

All the alloys prepared for this work were made from deoxidised copper, and, as tubes are made from both arsenical and non-arsenical copper, a series of each of these two kinds was prepared. In all, 91 alloys were made to cover, in each series, varying bismuth, selenium and tellurium contents. The non-arsenical series consisted of coppers containing for each nominal bismuth content of nil, 0·001, 0·002 and 0·003%, nominal contents of no selenium or tellurium, 0·01% tellurium, 0·01% tellurium plus 0·01% selenium, 0·02% selenium, 0·02% tellurium, 0·02% selenium plus 0·02% tellurium, 0·04% selenium, 0·04% tellurium, and 0·04% selenium plus 0·04% tellurium. The arsenical series included also nominal bismuth contents of 0·004, 0·005 and 0·006%. From each melt two billets were obtained, each weighing 92 lb., 2¾ in. diameter, and about 4 ft. 6 in. long.

The scheme of operations by which the billets were manufactured into tubes is shown in Table I. The uncropped billets were heated to 800°—850° C. in a coke-fired muffle having a sloping hearth, and it was possible to transfer each one in a few seconds from the furnace to the rotary piercer on which the shells were made. The time occupied in piercing each billet was about 22 secs. The tubes at 2 in. and 1⅝ in. internal diameter—that is, after both the first and second draws—were cut in halves, so that of those materials which it was possible to complete down to the finished size, four tubes from each billet were obtained.

TABLE I.—TUBE-DRAWING SCHEME.

2¾-in. diameter billet heated to 800°—850° C. and pierced to a shell of 3¼ in. external diameter with ⅜ in. wall thickness. Quenched in water. Ends trimmed.
1st cold-shouldering.
1st cold draw to 2 in. internal diameter × ⅜ in. wall thickness.
Annealed for 45 minutes at 680° C., quenched, pickled in 10% H_2SO_4, and washed. Trimmed and cut into halves.
2nd cold-shouldering.
2nd cold-draw, to 1⅝ in. internal diameter × ⅜ in. wall thickness. Annealed, quenched, pickled and washed. Trimmed and cut into halves.
3rd cold-shouldering.
3rd cold-draw to 1¼ in. internal diameter × 13 S.W.G. (0·092 in.) wall thickness. Trimmed (no anneal).
4th cold-shouldering.
4th cold-draw (taken hard) to 1 in. internal diameter × 15 S.W.G. (0·072 in.) wall thickness.

The products of the work were carefully examined, and the authors discuss the results of the investigation as follows :—

Non-Arsenical Copper.—In this series no failures occurred with bismuth contents up to 0·0035% in the absence of selenium and tellurium. Tensile test results on these were normal, and no failures occurred in either the hot- or cold-bend test, except in the copper containing 0·0035% bismuth, which cracked on bending at 600° C.

The presence of selenium in amounts up to 0·045%, in the absence of tellurium, did not give rise to any unusual effects, and there were no process or bend-test failures in these coppers, and the values obtained in the tensile tests were quite normal.

Most of the failures were associated with the simultaneous presence of bismuth and tellurium. In general, those materials in this series which failed in processing did not show very abnormal tensile test results. With bismuth contents up to and including 0·0025% tellurium to the extent of about 0·010% appeared to be without detrimental effect, but with this same tellurium content in the presence of 0·0034% bismuth, failures occurred in cold-shouldering. This effect seemed to be offset to some extent by the presence of selenium. With increasing amounts of tellurium, in the absence of selenium, its deleterious effect, which increased with increasing bismuth content, became more marked. So far as manufacturing processes were concerned, failures occurred in both hot- and cold-working operations, and cracking occurred in hot-bend tests.

Arsenical Copper.—No process failures in either hot or cold operations occurred with coppers free from selenium and tellurium, but containing up to 0·0065% bismuth (heats 37 to 43, Table III), although in those of higher bismuth content test-pieces cracked in the 600° C. bend test, and inferior tensile properties were obtained with the coppers containing 0·0051 and 0·0065% bismuth.

Although the presence of selenium, in the absence of tellurium, did not give rise to any hot failures over the whole range of bismuth contents considered, process failures in the cold increased in number with increasing selenium and bismuth contents. In those members of these two series with higher bismuth contents, cracking occurred in the 600° C. bend test, and low results were obtained in tensile tests.

The presence of a nominal 0·01% tellurium addition did not appear to have any adverse effect on either the hot- or cold-working properties, or on the bending or tensile properties, except on one composition containing 0·012% tellurium and 0·0044% bismuth, in which failures occurred at the second cold-shouldering. With increased tellurium contents, in the absence of selenium, the process failures were much more numerous and increased with rising

bismuth content. With the highest tellurium contents, all of the heats containing bismuth failed in hot-piercing.

As in the non-arsenical series, the presence of selenium appeared to counteract to some extent the apparently deleterious effect of tellurium. With the highest ranges of selenium and tellurium contents the effect was not so apparent.

The results on the whole show that tellurium exerts a more marked deleterious effect than selenium. While bismuth, in the absence of either of these two elements did not appear to effect the hot- or cold-working properties of the metal, although it was not without effect in the hot-bend test and on the tensile test results, increasing amounts of bismuth accentuated the harmful influence of selenium and tellurium when present either alone or together. In general, this effect of these elements would appear to be more marked in arsenical than in non-arsenical copper.

A Thought for Silicon-Manganese Steel

By Bernard Thomas, F.Inst.P., F.Inst.F.

Silicon is used in practically all commercial steel ingots and castings as a deoxidiser, but its use as a true alloying element has been somewhat limited even though it has characteristics that merit a wider use. Since silicon is not in short supply, brief consideration is given to its use in conjunction with manganese.

IN a recent issue of this journal,* results of tests were described which had been taken on carbon steels of various manganese percentages with a view to illustrating the relative hardening value of such steels of non-alloy content. On this occasion tests are described which have been made on silicon-manganese steel, silicon not being included in the list of elements in short supply.

Apart from its use as a spring steel—particularly of the leaf, or laminated, variety, silicon-manganese steels are not as well known as their properties really merit. The B.S. En. series classify two types, the specifications of which are given in Table I.

TABLE I.
B.S. SPECIFICATIONS OF SILICON-MANGANESE STEEL.

Element.	B.S. En.45.	B.S. En. 46.
	%	%
Carbon	0·50—0·60	0·33—0·50
Silicon	1·50—2·00	1·50—2·00
Manganese	0·60—1·00	0·60—1·00
Sulphur	0·05 max.	0·05 max.
Phosphorus	0·05 max.	0·05 max.

The higher carbon specification, En. 45, is designed for oil-hardening and tempering, and the En. 46 for water-hardening and tempering.

In a well-rolled section of silicon-manganese steel which has received plenty of "work"—otherwise reduction during rolling, a fibrous structure is developed which resists fatigue stresses to a greater degree than many of the better known alloy steels. Heat-treatment response is good, the relatively high potential carbon and manganese contents assisting in this direction.

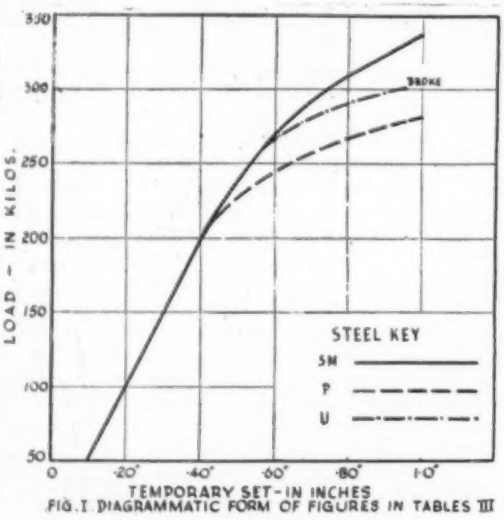


Fig. 1.—Diagrammatic form from data in Table III.

No heat-treatment temperatures are laid down in the specification, but the effect of silicon is to raise the quenching temperature slightly, and for En. 45 the AC_3 point is roughly 800°—820° C. For general purposes, however, 850° C. may be employed for En. 45 and 870°—900° C. for En. 46, in view of the lower average carbon content. Some users advocate up to 950° C. as a suitable quenching temperature, but this is inadvisable as the grain tends to coarsen at such figures.

As in the case of the manganese steels cited previously, tests were carried out on strips of material prepared in exactly similar manner as described on p. 199 of the October issue of this journal. In view of the correspondence passed on the subject, however, it should be explained that many thousands of tons of steel are consumed annually in the manufacture of a certain class of tool which, without naming, will be recognisable by the actual manufacturers concerned from the dimensions of the test-strips employed

With such tools it has been found that the normal methods of physical testing provide figures which have little bearing on the heat-treated results, and the procedure employed as described has been developed by the writer through necessity accordingly.

On this occasion test-pieces were quenched in oil in orden to conform to the practice as would obtain in the treatment of the particular tools involved. The latter qualification also explains the use of 425° C. as the tempering temperature.

To provide comparison with the silicon-manganese steel under discussion, two others of carbon types were used and the three analyses are quoted in Table II.

The elements silicon and manganese are shown in bolder type in the table for greater ease of assimilation.

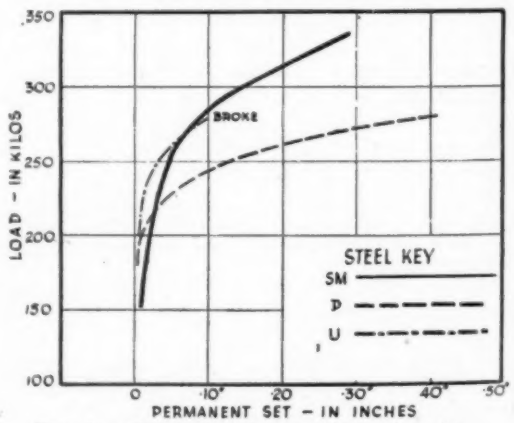


Fig. 2.—Diagrammatic form from data in Table IV.

TABLE II.
COMPOSITIONS OF THREE STEELS EXAMINED.

Steel Reference.	S.M.	P.	U.
	%	%	%
Carbon	0·51	0·51	0·82
Silicon	2·00	0·163	0·091
Manganese	0·91	0·92	0·33
Sulphur	0·36	0·034	0·005
Phosphorus	0·45	0·040	0·025

* METALLURGIA, October, 1942, p. 199.

Amounts of temporary deflection or set under load were again recorded, as was also the permanent deflection after load had been withdrawn, the actual readings being shown in Tables III and IV.

TABLE III.

TEMPORARY DEFLECTION, OR SET, UNDER LOAD. STRIPS QUENCHED FROM 850° C. IN OIL AND TEMPERED 30 MINS. AT 425° C.

Steel Reference: Strip Thickness.	S.M. 0·125 in.	P. 0·124 in.	U. 0·124 in.
Load in Kilos.	In.	In.	In.
50	0·085	0·10	0·10
100	0·19	0·20	0·20
150	0·30	0·30	0·30
180	0·36	0·37	0·35
200	0·41	0·41	0·40
220	0·45	0·47	0·46
240	0·50	0·57	0·50
260	0·56	0·74	0·57
280	0·63	1·00—Indef.	0·69
300	0·75	—	0·95
320	0·92	—	1·00 and Broke
340	1·00—Indef.	—	—

In the case of Table III, it will be observed that the temporary deflection, or set, under load, which serves as comparator in indication of strength, reveals the "straight" lower carbon steel, Ref. P, as the weakest of the three. Fig. 1, which gives Table III in diagrammtic form, shows clearly the falling-off in this respect above load of 200 kilos. Steel Ref. U manages to compete with the silicon steel up to 260 kilos. loading, and then falls away also to leave the latter as the strongest under load. An added feature is that the higher carbon steel, Ref. U, broke at 1·00 in. deflection, indicative of brittleness, while the silicon-manganese material withstood the same test without rupture.

Turning to the figures in Table IV, it is curious to find that permanent deflection, or set, occurs after lighter loads with the silicon-manganese steel than with the other two. It should not be assumed, however, that this indicates "softness," as experience suggests in these tests that where such occurs it usually coincides with areas of martensite in the structure which have failed to break down to either troostite or sorbite. With actual tools, the remedy is either to re-temper any showing such signs at the same temperature, but for a longer time, or, alternatively, adopt a longer time initially after quenching. By the adoption of the former procedure the writer has known many thousands of "soft" tools to become the correct hardness and resilience, no rehardening being necessary.

TABLE IV.

PERMANENT DEFLECTION, OR SET AFTER REMOVAL OF LOAD. STRIPS QUENCHED FROM 850° C. IN OIL AND TEMPERED 30 MINS. AT 425° C.

Steel Reference. Strip Thickness.	S.M. 0·125 in.	P. 0·124 in.	U. 0·124 in.
Load in Kilos.	In.	In.	In.
50	—	—	—
100	—	—	—
150	0·005	—	—
180	0·015	0·005	—
200	0·02	0·01	0·005
220	0·03	0·030	0·01
240	0·04	0·085	0·02
260	0·055	0·19	0·045
280	0·08	0·41	0·10
300	0·14	—	Broke at next loading.
320	0·23	—	—
340	0·29	—	—

Turning to Fig. 2, in which the data of Table IV is plotted, it will be observed that beyond 220 kilos steel S.M. asserts its superiority of steel P, which latter runs out at fairly rapid rate to finish at a loading of 280 kilos. It is roughly at the same point that Ref. U begins to yield and falls below Ref. S.M., only to break when attempting to load to 300 kilos. In comparison, steel S.M. continues up to a loading of 340 kilos before the temporary deflection reaches a maximum of 1·00 in., and even then has a permanent set of only 0·29 in. without sign of fracture.

The superior strength of the silicon-manganese steel over that of the straight carbon "50" and "80" has been clearly demonstrated at a given heat-treatment temperature. That greater resistance to distortion with less risk of fracture is also a feature is further demonstrated by the permanent set figures and plottings. As a consequence of these results users may be encouraged to consider the utility of the silicon-manganese steels.

Thickness of test-strips are quoted as any appreciable difference in measurement affects considerably the results.

Provision of photomicrographs would have been a useful contribution, but, unfortunately, depleted staffs mitigate against many things one would normally do under ordinary circumstances.

Correspondence

Nitrided Cast Iron as an Alloy Steel Substitute

Dear Sir, The Editor, METALLURGIA.

The October issue of the United States technical journal, *Metals and Alloys*, contains an abstract of the above article which appeared in METALLURGIA. As our company is naturally interested in this subject, we wonder if it is possible to obtain more information and precise data concerning the special tools used. Can you send us a drawing of the clipper tool and also the analysis of the nitricastiron? And how was this heat-treated and nitrided? Are any of these tools now in operation? When were the first tools made, and how long have they been in service?

We thank you in advance for the courtesy of your co-operation.—Yours faithfully,

D. LANDAU,
Industrial Applications Engineer
The Nitralloy Corporation.

New York, U.S.A.
November 4, 1942.

Dear Sir, The Editor, METALLURGIA.

Many thanks for your letter of November 4, 1942, in which a number of questions is raised regarding my article in the July issue of METALLURGIA under the above title.

As apparently only an abstract of the article has been read, a copy of the original as published has been despatched to Mr. Landau, which answers part of his queries A print has also been despatched which shows details of four separate types of clipping tools used in nitricastiron (details of one of the clipping tools are reproduced here). I would add that the application could be extended to practically any type of tool used for clipping the "flash," or surround, which occurs in production of most drop forgings.

As regards the composition of the body material, a typical analysis of that employed is as under and was obtained on sand-cast production :—

Total carbon	2·63%	Phosphorus	0·097%
Combined carbon	1·03%	Chromium	1·61%
Graphitic carbon	1·60%	Aluminium	1·39%
Silicon	2·37%	Vanadium	Trace.
Manganese	0·59%	Titanium	Nil.
Sulphur	0·078%	Molybdenum	Nil.

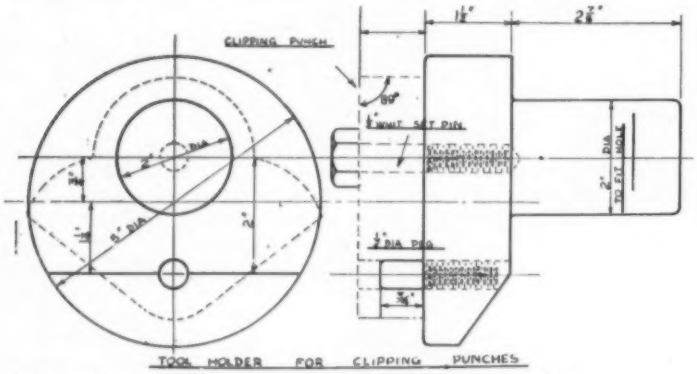
In all the cases as used by us the heat-treatment and nitriding was carried out as described in the article, the body hardness usually ranging from 248 to 285 Brinell (22·5 to 28·5 Rockwell C). If, however, we had sections of heavier dimensions with which to contend we should probably have quenched from approximately 875° C. in oil and tempered at 600°—650° C. for several hours, as the latter may be regarded more of a stabilising treatment than a tempering action.

At present none of these tools are in operation, the plant in question being engaged on work having a more direct connection with the war effort.

The first tools were made early in 1933, and in some instances those of initial production lasted as long as five years. Such life was doubtless assisted by the infrequency with which it was necessary to "touch up" the clipping tools between the various runs of the dies, and one set of

clipping tools would outlast a considerable number of pairs of dies.

It may be of interest to point out that the design of our tools, in which we set up the profile of the cutting edges in heavy relief, reduces considerably the machining and toolmaking costs of these plates, which offsets to a large extent the extra cost of manufacture which would otherwise obtain in comparison with those in other materials. An important point is the advisability of leaving a very



slight radius on the cutting edges. Theoretically these should be left sharp, but, logically, if this is done early wear through spalling occurs, and one usually finds that production continues with a radius formed roughly through same, and therefore such radius should obviously be embodied neatly in advance of nitriding.

In a previous article* I have shown that spalling on corners is due largely to double or treble nitride penetration, and if a radius equivalent to one-and-a-half sixty-fourths is employed, such areas are removed from the area likely to cause trouble in service. Assuming that the penetration occurs at right angles, this fact can be checked quite easily on a drawing-board.—Yours faithfully,

B. THOMAS,
Managing Director
Midland Heat Treatments, Ltd.

Wolverhampton.
November 26, 1942.

Hardness Testing of Heat-Treated Forgings

Dear Sir, The Editor, METALLURGIA.

In the above interesting article in your November issue, Mr. Thomas refers to the high values obtained for diamond hardness. He may be interested in a communication to the Institution of Automobile Engineers, which was written about twelve years ago, a copy of which is enclosed for him.

Rather curiously, Field Foster (Mechanical Testing of Materials, 1936 edition) says of the differences between shapes of impressions: "The effect introduces *an error* whereby worked metals give high results, and very workable metals will give low results."

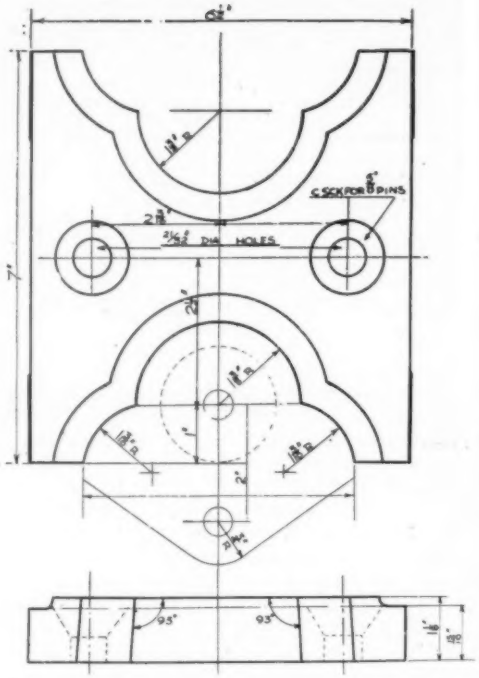
I suggest that the observed differences can be used to amplify the information given by other hardness tests, instead of being glossed over as defects in testing. Micrographs of the impressions are often interesting.—Yours, etc.

H. SPENCER KIPLING,
Laboratory, Wolseley Motors, Ltd.

Birmingham, 8.
December 8, 1942.

Dear Sir, The Editor, METALLURGIA.

I am indebted to Mr. H. S. Kipling for the interest taken in my article, under the above title, in your November issue, and for his courtesy in sending a copy of his communication to the Institution of Automobile Engineers. I had not previously read this communication, but I am in agreement with the data contained in it.



One of a series of similar components for which nitrided cast-iron clipping tools were used.

It is, of course, reasonably well known that discrepancies are bound to arise between ball and diamond testing inasmuch that errors are likely from ball deformation and surface disturbance.

The effect of cold work on steel frequently results in the crushing of the grains, but as this is largely superficial, unless carried out to an abnormal extent, one finds that the low-loading hardness testing devices, such as those which employ the diamond indenter, may record such cold working in terms of greater hardness, while the 10 mm. ball, under the full 3,000 kg. load, can break through the "skin" so formed to reach the unaffected metal beneath, with the result that a low-hardness figure is returned. This is in keeping with the expression made by Field Foster in the book mentioned, which refers to high results obtained on worked metals.

Beyond the above, as mentioned at the foot of the second column on page 28 of your November issue, reference is made to a "skin" hardness which occurs with many of the nickel-chromium-molybdenum steels on quenching in water after tempering, as is the usual procedure. Steels such as 4S 11, S 65, etc., are typical of those affected in the manner described. The effect of such quenching after tempering becomes even more pronounced where exaggerated thick and thin parts may obtain such as are mentioned in the opening paragraph of the article.

I quite agree with Mr. Kipling that such differences should certainly not be glossed over as defects in testing, but rather employed, if used intelligently, as a means of determining the condition in which any particular material being tested may exist.

I suggest, however, that the important point, in this question of hardness testing, remains as contained in the summary of the article, that the consignor and consignee should have some agreed arrangement regarding the use of similar methods of testing, otherwise unwelcome discrepancies are inevitable.—Yours, etc.,

BERNARD THOMAS,
Managing Director.
Midland Heat Treatments, Ltd.

Wolverhampton.
December 8, 1942.

* METALLURGIA, November, 1935, p. 28.

The Basic Open-Hearth Process To-Day

Part IV. (*contd*).—Pitside Practice, Instruments and Fuel

By W. Geary

In recent years great progress has been made in improving pitside practice, and in this article attention is directed to this important part of steel production. The discussion is concerned mainly with ladles, stoppers and nozzles, teeming speed and temperature, ingot moulds, mould preparation, feeder heads, bottom pouring, instruments, molten steel temperature and fuel, including producer, mixed, and coke-oven gases.

Molten Steel Temperatures

In the last two years the accurate measurement of the temperature of molten steel in the bath has been brought into the realm of practical steelmaking. The work leading up to this gratifying result was initiated by the Liquid Steel Temperature Sub-Committee, a sub-committee of the Heterogeneity of Steel Ingots Committee. They critically examined the results obtained from optical pyrometers and from the Fitterer silicon-carbide/graphite thermocouple, and after due consideration of the limitation of these instruments decided to follow up successful experiments that had been made with rare metal couples. The result of the work is Dr. Schofield's "Quick-Immersion" thermocouple. Various types of mounting may be used, according to whether the instrument is to be used in the furnace, ladle or elsewhere. Fig. 6 shows the couple mounted on a trolley, which is the general method adopted for measuring the temperature in the bath of fairly large furnaces. The lower end of the extension piece that carries the hot end of the couple is shown in Fig. 7. The end of the steel tube is covered with either a diatomaceous brick or a carbon block, which are resistant to the corrosive action of acid and basic slags respectively, and will stand a number of successive immersions. The hot end of the thermocouple is insulated with twin-bore silica, except for a few inches of bare wire terminating in the junction, and is contained in a silica tube which is within a thin steel tube. Although some work still remains to be done in regard to the temperature explorations of different types of furnace, particularly in the case of large furnaces, control of temperature in the bath is definitely being achieved. The extent to which the temperature varies throughout the mass of molten steel is, to some extent, decreased by making the measurement a few minutes after vigorous rabbling of the bath. It is necessary for each works to correlate temperatures in the furnace with those taken at later stages, in the launder, the ladle, etc. An incidental result of the success achieved by this pyrometer is the enhancement of the value of the disappearing-filament optical pyrometer. By taking a number of simultaneous readings with both types of instrument it has been possible to correct the emissivity factors for a number of steels, and thus to increase the accuracy of the determination made by the convenient optical instrument.

Fuel

To the steelmaker there is nothing in the details of plant or practice that is unimportant; certain things are necessary, others merely desirable: but of all the essential requirements in a melting shop the prime one is an adequate supply of fuel. It is the mainspring of the plant and one of the biggest items in the cost of operation. The heat problem of the open-hearth furnace is to get the most rapid melting and superheating of the steel possible, in order to get the maximum furnace efficiency. To this end the endeavour of operators is to secure the maximum flame temperature, the best possible heat transfer, and the minimum loss of heat. The production of maximum flame temperature for a given gas is dependent upon the preheat of the gas and air, and upon the design of the burner in the furnace. This latter point was discussed by the author in a previous article in this series.[11] Preheating of gas and air is normally done by means of checkers, the majority of operators favouring an air preheat temperature of about 1,250° C.: producer gas is preheated to about 200° C. lower, and mixed blast-furnace and coke-oven gas to about 50° C. lower.

The development of the highest possible flame temperature in the furnace does not necessarily simply that the maximum heat transfer is being obtained. It has been established that heat transfer to the charge depends to a considerable extent on the luminosity of the flame. The charge in a furnace receives heat by both direct conduction and by radiation. A flame that is luminous is so by virtue of the incandescent carbon particles either entrained or resulting from the cracking of the hydrocarbons in the gas. The radiant energy from a flame depends on the density of population of these particles within the flame and also upon the thickness of the flame. Such a flame is one which the melter describes as having good body. It ensures the maximum transfer of radiated heat to the charge, and at the same time permits the downward passage of reflected heat from the roof. Thus the ideal combination of hot charge and cool brickwork is realised.

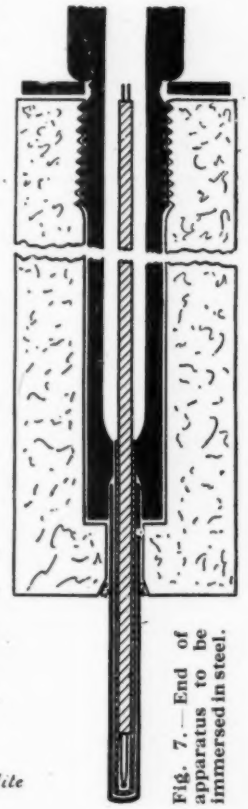


Fig. 7.—End of apparatus to be immersed in steel.

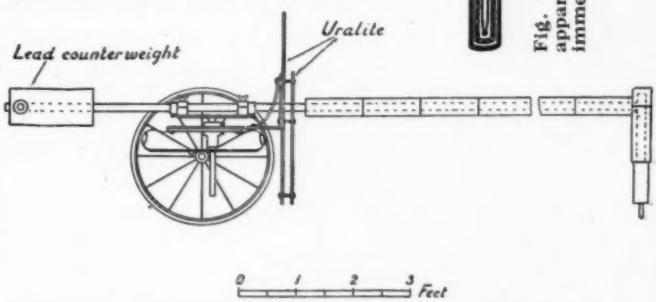


Fig. 6.—Quick-immersion thermocouple mounted on a trolley.

The fuels which most readily burn with a luminous flame are producer gas and fuel oil. The latter fuel is not much used in this country, and the former is commonest. Of the furnaces reported on in the Symposium on Steelmaking, 65% were fired with straight producer gas, 24%

11 METALLURGIA, 1942, Aug., vol. 26, No. 154, pp. 125–126.

with producer plus coke-oven gas, 3·5% with straight coke-oven gas, with and without tar, and 7·5% with mixed gas. These figures, published in 1938, must be interpreted with care. The papers of the Symposium do not cover all the melting furnaces in the country, andamong the unreported plants there will be a large proportion of standard furnaces fired with producer gas. Thus, the total percentage of furnaces fired with producer gas, with or without addition of coke-oven gas, would very probably be greater than 89%. The use of alternative fuels is of comparatively recent development in this country. The first large-scale attempts to use mixed gas were in the middle of the 1920's. At the outbreak of the present war there were two large plants in which the furnaces were fired entirely by mixed gas, while a third plant, similarly fired, has recently gone into production. The number of furnaces using cold coke-oven gas is very small, probably not more than eight in all. The author believes that the number of furnaces fired with producer gas will decrease. There is a definite trend towards the construction of integrated iron and steel works comprising coke-ovens, blast-furnaces, melting shops and rolling mills, and there is a great incentive in such a works to complete the operations with scarcely any coal, except that coming to the coke-ovens. The reader interested in this subject is recommended to study the work of Mr. W. J. Brooke, at Normanby Park.[12] The chief users of 100% producer gas are those works remote from coke-ovens and blast-furnaces: coal is their most convenient fuel. The development of coke-oven gasgrid systems on the Continental model would, however, provide an alternative convenient supply of fuel, and since in the last few years the technique of using this fuel has been worked out, it is possible that some independent melting shops will, in future, operate with coke-oven gas piped from a distance.

Producer Gas.—British gas producer practice was exhaustively examined by Mr. F. Clements in 1923.[13] Since that time the main change that has taken place is in the increasing mechanisation of gas plant and in the wider range of coals used. Research on gas producer practice in all its aspects has been accelerated during the last few years; the work has been widely distributed over a number of organisations and co-ordinated by the Technical Department of the British Iron and Steel Federation.

It is impossible to underrate the importance of a good coal supply. Screening should be accurate and the chemical analysis within prescribed limits. A low-sulphur content is one of the chief requisites in a gas coal. Table I is taken from a paper by C. H. Herty, Jr., and shows the amount of sulphur which, existing in various fuels, is neutral to scrap of certain sulphur content.

TABLE I.

Sulphur in Scrap, %.	"Neutral" Sulphur in Fuel.		
	Coal (for Producer Gas) % Sulphur.	Tar or Oil % Sulphur.	Coke-oven Gas: Sulphur, gr./100 cu. ft.
0·02	0·38	0·40	97
0·03	0·49	0·51	123
0·04	0·59	0·61	150
0·05	0·67	0·69	169
0·06	0·73	0·75	183
0·07	0·77	0·79	194

The design of gas mains and dust catchers has been the subject of recent work, resulting in the improvement of existing installations. Perhaps the most interesting feature of gas-main practice is the tendency to leave the "modern" practice of a central gas plant with a common main feeding the melting furnaces, and go back to the older idea of a separate main to each furnace with its own producers. This tendency was already apparent in 1938.[14] It was then reported that in America the producers were under the control of the melter on the furnace, who was able to adjust them according to the needs of his furnace. The most recent notable change-over from common main to isolatiou is that reported from Witkowitz.[15]

Gas producers working for steel melting furnaces should be worked not only with the object of making gas of high-calorific value, but also of carrying the maximum amount of tarry matter into the furnaces. The tarry vapours and soot present in producer gas are chiefly responsible for the high luminosity which makes it, in spite of its comparatively low calorific value, the most widely used fuel in open-hearth furnaces.

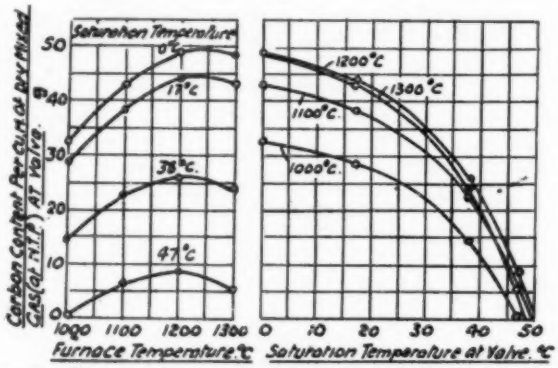


Fig. 8.—Free carbon content of preheated mixed gases (Heiligenstædt).

Mixed Gas.—This term has come, by common usage, to mean a mixture of blast-furnace gas and coke-oven gas. On occasion producer gas is added to mixed gas, when the complete fuel is usually referred to as three-gas. A recent valuable paper dealing with the subject of gaseous fuels for melting furnaces, with particular reference to the problems encountered in using mixed gas, was published by Wright and Pearson.[16] Tables II and III and Fig. 8, taken from their paper, are here reproduced because they illustrate points of great importance in the use of mixed gas for steelmaking.

TABLE II.

	CO_2.	O_2.	Cn-Hm	CO.	CH_4.	H_2.	N_2.	Theoretical B.Th.U. cub. ft.
Producer gas.....	4·0	—	0·4	29·0	2·6	12·0	52·0	Apprx. 160
Mixed BF/CO 2/1....	8·35	0·15	1·0	20·35	8·66	20·0	41·53	240
Mixed BF/CO 3/1....	9·0	0·10	0·75	22·00	6·50	15·5	46·15	205

TABLE III.

Sampling Time.	Furnace Temp. °C.	CO_2.	O_2.	Cn-Hm.	CO.	CH_4.	H_2.	N_2.	—
A_1, 10 mins.....	—	3·6	0·6	2·7	6·1	28·0	55·0	4·0	Before
A_2, 10 mins.....	940	3·4	0·6	2·4	6·4	28·0	55·0	4·2	After
B_1, 6 mins.....	—	3·6	0·6	3·0	6·4	29·0	55·4	2·0	Before
B_2, 6 mins.....	1,040	3·4	0·6	0·2	6·4	26·4	60·8	2·2	After

Table II gives an analysis of clean producer gas and calculated analyses of mixed gas for two ratios before regeneration. The leaner mixture of the 3/1 ratio is infrequently used; it is seldom found that the ratio rises above 2½/1, whilst mixtures having a calorific value of 300 B.Th.U. per cubic foot have been satisfactorily worked.[17]

Mixed gas requires preheating to develop luminosity. The breakdown of hydrocarbons starts at about 800° C. and reaches a maximum at about 1,200° C. Table III shows the effect of heating coke-oven gas and taking samples after the gas had been heated to 940° C. and 1,040° C.

12 W. J. Brooke, *Journal of the Iron and Steel Institute*, 1933, No. 2.
13 F. Clements, *Journal of the Iron and Steel Institute*, 1923, No. 1, p. 97.
14 Symposium on Steelmaking, *Iron and Steel Institute Special Report*, No. 22, p. 440.
15 A. Rotter, *Stahl u Eisen*, 1941, vol. 61, Oct. 9—Oct. 16.
16 W. B. Wright and T. F. Pearson, *Journal of the West of Scotland Iron and Steel Institute*, Session 1941–42.
17 Symposium on Steelmaking, *Iron and Steel Institute Special Report*, No. 22, p. 431.

The flame of B_2 had a markedly greater luminosity than that of A_2. It is usual, therefore, for the gas checkers of a mixed-gas furnace to be kept at 1,200° C. or more, in order to ensure the maximum formation of carbon particles. Unfortunately, if the gases are wet, the free carbon can combine with the water vapour to give hydrogen and carbon monoxide; this reaction proceeds also at a maximum rate at about 1,200° C. Fig. 8 shows how the precipitation of free carbon varies under altering conditions of preheat and saturation. It is important, therefore, to keep the moisture content as low as possible. J. B. R. Brooke reported[18] that he met the condition by ensuring that the temperature of the blast-furnace gas is kept below 18° C. before entering the gas valve. Reference to Fig. 8 will show that a high degree of carbon precipitation can be obtaned.

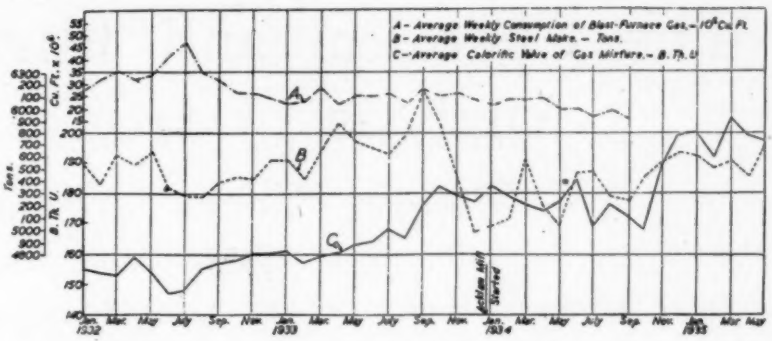


Fig. 9.—Influence on output of decreasing proportion to blast-furnace gas in mixture.

In order to maintain the high temperature in the gas regenerators, special port designs or dampering devices are sometimes considered necessary. Some of these have been mentioned in a previous article.[19]

Three-Gas.—This practice is used occasionally, either with the object of providing flexibility where the mixed gas supplies are insufficient, or as a means of increasing flame luminosity. It did not, in the author's experience, prove to be a satisfactory fuel. He discussed results in 1937,[20] which showed a steady increase in plant output as the blast-furnace gas was gradually diverted from the melting furnaces to other purposes. Fig. 9 is taken from the above paper.

Coke-oven Gas.—The use of coke-oven gas as an addition to producer gas has increased in recent years. As has been mentioned, 24% of the furnaces quoted in the Symposium on Steelmaking were fired by this means. It is a particularly useful addition to make to a lean producer gas, and to use in long furnaces. It is not possible, however, to make very large coke-oven gas additions, since the gas ports would then become too big for the gas volume entering; the flame would lose velocity, and the gas would burn erratically in the furnace. In some open-hearth plants the addition of coke-oven gas is made only "when available." Objection can be made to this practice on the ground that a furnace cannot be designed to be efficient under varying fuel conditions; but there is, in the author's opinion, a good case to be made for adding coke-oven gas to producer gas when the supply of both is constant, and furnaces can be designed for the efficient burning of the mixture.

Cold coke-oven gas is used as the principal fuel on furnaces in three plants in this country, and all were described in the Symposium on Steelmaking. It has proved to be an eminently satisfactory fuel—it is clean, convenient and economical. Its one drawback is that it is incapable of working alone where hot-metal practice, involving high-metallurgical load, is used. It is impossible (at any rate at the present state of knowledge of slags) to suppress foaming unless the gas is given luminosity. An addition of tar is the common means adopted, and it provides a complete solution to the problem.

The author is indebted to the management of Dorman, Long and Co., Ltd., for permission to publish this series of articles.

18 J. B. R. Brooke. *Iron and Steel Industry*, 1935, vol. 9, Oct., pp. 3–5.
19 METALLURGIA, 1942, Aug., vol. 26, No. 154, pp. 126–127.
20 W. Geary. *Iron and Steel Institute*, 1937, No. 2, p. 238 P.

Rates of Cooling and Heat Transfer Figures when Patenting Steel Wire in Various Cooling Agents

THE quick cooling of steel wire from temperatures above the A_3 point, in order to produce a structure suitable for drawing to a high-tensile strength, has been studied by Lueg and Pomp.* The object of the investigation was to determine whether and under what conditions baths of molten salts or of salt mixtures could be used for patenting steel wire, instead of the more usual baths of molten lead.

Spherical specimens of scale-proof steel with thermo-elements in the centre were heated to 800°–950° C. and dropped into baths of cooling agents of 250° to 550° C. temperature. The temperatures observed were plotted against times. The cooling agents used were lead, potassium nitrate, sodium nitrate, and a mixture of equal parts of these two nitrates. The cooling rates were observed point by point from the curves of the course of temperatures and plotted against the corresponding differences between the temperatures of the centres of the specimens and of the bath.

The cooling capacity of lead was generally somewhat higher than that of the salt mixture, although at first the cooling rate was higher in the salt than in the lead-bath with equal temperatures at the beginning and at the end in both cases. The two nitrates and their mixture do not differ very much with regard to their cooling capacity. While the rate of cooling in the lead-bath increased considerably with increased stirring rate of the test specimens' this influence was much lower with the salt-baths. It was concluded from the course of the cooling capacities that the salt-baths tested can be used for patenting steel wire if the temperature of these baths is kept lower than is necessary with lead-baths under otherwise equal conditions.

Conclusions drawn from the cooling capacity with regard to the formation of the structure and the tensile strength of the steel wire could be confirmed by dip-patenting of pieces of steel wire, containing 0·58% carbon, in various cooling agents and at various temperatures of the baths.

The heat transfer figures were found from a comparison of the measured rates of cooling with those calculated according to the laws known for the transmission of heat. It appeared that, when cooling in liquid lead, the heat transfer figure was independent of the difference of temperature between specimen and bath; also it did not change actually during the process of cooling down, but it increased almost proportionately to the rate of stirring. With the salt-bath, however, the heat transfer figure depended on the difference of temperature at the beginning of the cooling-down process as well as during this process. This could be taken from a lowering of the cooling-down capacity in connection with an increasing difference of temperature at the beginning and from a decrease of the rate of cooling during the cooling-down process. The influence of the stirring rate, however, was much lower with the salt-bath than with the lead-bath.

* *Mitt. aus dem Kaiser-Wilhelm Institut. für Eisenforschung zu Düsseldorf* vol. xxiii, No. 64.

The Chemical and Physico-Chemical Analysis of Iron and Steel

Twelve Years' Advancement

By E. C. Pigott

Part II. (*Contd.*)—Papers Describing the Determination of Single Constituents

Tin

Many steels contain small amounts of tin introduced from raw materials, especially from detinned scrap. Except in tool steels, such amounts (<0·10%) have no serious effect on mechanical properties, but larger percentages are detrimental. In cast irons, tin inhibits graphitization. Even in small amounts, tin interferes with a number of methods for other elements. In the estimation of the element in steel, tungsten complicates its isolation through causing adsorption. In the iodometric method, interference is caused by arsenic, chromium, molybdenum and vanadium. Solution of ferrous sample in dilute sulphuric acid may leave as much as a quarter of the tin in the residue whilst volatilization losses occur on evaporating hydrochloric acid solutions.

Andrew and Peile. *J. Iron Steel Inst.*, 1933.
(Gravimetric and volumetric procedures for small amounts in steel are discussed.)

Evans. *Analyst*, 1932, **57**, 362–8.
(Precipitation as sulphide with separation from copper, lead, etc., by means of sodium hyposulphite.)

Mischonsniky. *Congr. chim. ind., Compt. rend. 18me congr.*, Nancy, Sept.-Oct., 1938, 438–45.
(Rapid determination in iron and steel.)

Rousseau. *Chimie et Indus., Special No.* 157–61, March, 1932.
(Decomposition in 3N–HNO_3 and examination of residue; also in tungsten steels.)

Scherrer. *Bur. Standards J. Res.*, 1932, **8**, 309–20.
(In tungsten and vanadium steels; distillation methods, since recommended by United States Steel Corporation.)

Scott. *Chemist-Analyst*, 1937, 26, 62.
(Rapid iodometric method involving reduction by means of aluminium.)

Sullivan. *Metals and Alloys*, 1935, **6**, 1934.
(In open-hearth steel.)

Taylor-Austin. *B.C.I.R.A. Res. Rep.*, 1940, 6036.
(In cast iron.)

In Ferro-Molybdenum.

Shkotova. *Zavod. Lab.*, 1937, **6**, 745.
(Ether separation followed by precipitation as sulphide and ignition to SnO_2.)

In Ferro-Tungsten.

Kiefer. *Z. anal. Chem.*, 1932, **88**, 243–9.
(Fusion with alkali peroxide and iodometric titration after reduction with aluminium in dil. HCl.)

Spectrographic.

Breckpot and Mevis. *Ann. soc. sci.*, Brussels, 1934, 54B, 299–8.

Brode. *Proc. Amer. Soc. Testing Materials*, 1935, **35**, 47–56.

Warga. *Univ. Pittsburgh. Bull.*, 1937, **34**, 28–30, 335–9.

Titanium

The various papers contributed are representative of well-known methods, and describe valuable modifications. The fundamental reaction of the more generally used processes is still the formation of yellow pertitanate by means of hydrogen peroxide. The photo-electric absorptiometer is preferable to visual comparison for measurement of the colour-intensity, and Pinsl describes the use of selective filters to overcome the interference of colorations due to columbium and vanadium. In another photometric method, evolved by Klinger and Koch, the coloration is produced by chromotropic acid, which yields no colour with columbium or tantalum.

In the volumetric methods, a trivalent salt is furnished by means of nascent hydrogen, and chromous chloride and amalgams are proposed as reductants.

A modification of the method of hydrolysis with sodium thiosulphate consists in ensuring complete precipitation by applying the procedure in the presence of aluminium. Cunningham has devised an important cupferron method for alloy steels.

In selecting a suitable method, it will be remembered that chromium, vanadium and molybdenum, which interfere in the hydrogen peroxide colorimetric method, may be removed by fusion with alkali carbonate; that chromium, copper, tin and molybdenum, which are precipitated by thiosulphate, may (with iron, nickel and cobalt) be removed by means of the mercury cathode; and that cupferron serves to separate the titanium from ferrous iron, aluminium, chromium, molybdenum, nickel, cobalt, manganese, boron, phosphorus, and beryllium. In the presence of zirconium, hydrolysis with thiosulphate fails to reach completion, but phenyl-hydrazine is effective. Aqua regia and nitric acid are less effective than perchloric acid or sulphuric acid as solvents for titanium in iron and steel.

PRECIPITATION METHODS.

Arend. *Z. anal. Chem.*, 1932, **89**, 96.

Arend and Schnellenbach. *Arch. Eisenhüttenw.*, 1930, **4**, 265.
(Precipitation with BaC_2, fusion with Na_2C_2 and final precipitation with oxine.)

Bagshaw. *J. Soc. Chem. Ind.*, 1938, **57**, 260.
(Measurement of pertitanate in Lovibond tintometer after separation with cupferron.)

Cunningham. *Ind. Eng. Chem. Anal. ed.*, 1933, **5**, 305.
(In plain and rich alloy steels by cupferron separation completing (i) with H_2O_2); (ii) by titration with $KMnO_4$ following reduction with Zn; or (iii) by weighing as TiO_2.)

Duimov and Volodina. *Zavod. Lab.*, 1934, **3**, 1065.
(Review with reference to Cunningham's method.)

Lur'e. *Zavod. Lab.*, 1934, **3**, 1127.
(Precipitation with $Na_2S_2O_3$ in presence of Al.)

Sukhenko. *Zavod. Lab.*, 1934, **3**, 499.
(In special steels; precipitation by NH_4OH after oxidation of Cr with $(NH_4)_2S_2O_8$, and then titration with $FeCl_2$ following reduction with Zn in HCl.)

Taylor-Austin. *B.C.I.R.A. Res. Rep.*, 1938, 2033.
(In plain and alloy cast iron.)

PHOTOMETRIC.

Kenigstul. *Zavod. Lab.*, 1940, **9**, 1203.
(In cast iron; H_2O_2 coloration.)

Klinger and Koch. *Arch. Eisenhüttenw.*, 1939, **13**, 127.
(Review; estimation by means of chromotropic acid; Cb and Ta do not interfere.)

Pinsl. *Angew. Chem.*, 1937, **50**, 115.
(H_2O_2 method with selective filters.)

Sokalova. *Avtiipromysplennost*, 1939, No. 3, 52.
(H_2O_2—H_2SO_4 method.)

ELECTROLYTIC.

Dymov and Volodina. *Zavod. Lab.*, 1936, **5**, 1047.
(Hg-cathode separation, precipitation with cupferron, fusion with Na_2CO_3 and formation of pertitanate with H_2O_2.)

Kar. *Metals and Alloys*, 1935, **6**, 156.
(In chromium steels and alloys.)

Shportenko. *Zavod. Lab.*, 1939, **8**, 96.
(In ferro-titanium; Hg-cathode separation.)

Strubl. *Collection Czechslov. Chem. Commun.*, 1938, **10**, 466.
(Polarographically with dropping Hg-cathode).

POTENTIOMETRIC.

Brintzinger and Rost. *Z. anal. Chem.*, 1939, **117**, 1.
(In ferro-titanium.)

Klinger, Stengel and Koch. *Arch. Eisenhüttenw.*, 1935, **8**, 433; *Tech. Mitt. Krupp*, 1935, **3**, 41.
(In steel, alloys, slags and ores; volumetrically after reduction with Zn and $CrCl_2$ in 1 : 1 HCl.)

Martynchenko and Shimko. *Zavod. Lab.*, 1936, 1297.
(In ferro-titanium, ores, and slags.)

MISCELLANEOUS.

Budakov. *J. Applied Chem.*, Japan, 1934, **37**, Supp; binding, 754.
(In silicates by fusion with Na_2CO_3 then H_2O_2.)

Duez. *Bull. Assoc. Tech. Fonderie*, 1934, **8**, 570–1.
(In cast irons and steels containing vanadium by means of prepared "blanks.")

Johnson. *Iron Age*, 1933, 132, No. 8, 16.
(Rapidly in alloy and plain steels.)

Klinger. *Arch. Eisenhüttenw.*, 1934, **7**, 551.
(In high percentage ferro-silicon.)

Panchenko. *J. Applied Chem.* (U.S.S.R.), 1935, **8**, 361.
(Iodometrically by means of liquid amalgams.)

Simpson and Schumb. *Ind. Eng. Chem. Anal. ed.*, 1933, **5**, 40.
(Methods for Ti appended to paper on Zr.)

Toshiro. *J. Chem. Soc.*, Japan, 1932, **53**, 13.
(Iodometrically by means of liquid amalgams.)

Tsinberg. *Zavod. Lab.*, 1937, **6**, 358.
(Total Ti by decomposition with 1 : 2 H_2SO_4; TiO_2 by decomposition with 1 : 2 HNO_3.)

SPECTROGRAPHIC.

Bruk and Sorokina. *Bull. acad. sci. U.R.S.S., Sér phys.*, 1940, **4**, 23.

Schliessmann. *C.A.*, 1935, 79.

Tungsten

The development of photometric methods for many accompanying elements has simplified the main problem—namely, the examination of the precipitated tungstic oxide for contaminants, which consist of Fe, Cr, V, Si, Cl, Ta, Mo, Ti, Zr, P, and Sn. Contamination is said to be minimised by oxidising only very slowly, and, in the case of vanadium, oxidation with hydrogen peroxide at about 70° C. is preferable to the usual treatment with nitric acid.

An interesting advance is that of evaporation with perchloric acid after the customary solution of the sample in hydrochloric acid or dilute sulphuric acid.

Progress has also been made in the estimation of small amounts of tungsten, precipitation with α-benzoin-oxime in the presence of molybdenum, as described by Knowles (*Nat. Bur. Stand. J. Res.* 1 (1932), **9**, being complete within 10 mins. in contrast to the 24 hours or so required for the cinchonine precipitation.

Determination by spectrographic means is now well established.

REVIEW.

Yagoda and Fales. *J. Amer. Chem. Soc.*, 1938, **60**, 640.
(Analytical chemistry of tungsten.)

METHODS.

Campo and Sierra; *Anales. soc. espan. fis. quim.*, 1933, **31**, 356.
(Titration of alkali tungstate with benzidine, using methyl red.)

Chatterjee. *J. Indian Chem. Soc.*, 1940, **17**, 359.
(WO_3 treated with dilute glycerol and NaOH, excess alkali being determined by titration with HCl, using phenolphthalein.)

Clauberg and Behmenburg. *Z. anal. Chem.*, 1936, **104**, 245.
(In alloy steels by means of $HClO_4$.)

Fedorov. *Zavod. Lab.*, 1940, **9**, 1319.
(Analysis is facilitated by preliminary heat-treatment.)

Gutman and Gokhfel'd. *Zavod. Lab.*, 1938, **7**, 598.
(In small amounts by Clauberg and Behmenburg method.)

Miloslavskii and Gurevich. *Zavod. Lab.*, 1936, **5**, 1170.
(Micro-colorimetric as tungsten-blue.)

Seuthe and Schaefer. *Arch. Eisenhüttenw.*, 1937, **10**, 549.
(Decomposition in 1 : 3 $HClO_4$; 7 refs.)

Stahl and Fried. *Arch. Eisenhüttenw.*, 1935, **9**, 499.
(Special apparatus for rapid determination in chromium steels.)

Wdowiszewski. *Z. anal. Chem.*, 1931, **87**, 36.
(Weighed as H_2WO_4; purified by precipitation with benzidine.)

PHOTOMETRIC.

Bogatzki *Z. anal. Chem.*, 1938, **114** 170.
(A solution of 0·5 g. sample in H_2SO_4 + H_3PO_4 + HNO_3 is treated with $SnCl_2$ and hydroquinone in H_2SO_4; Ti produces a similar (red) colour.)

SPECTROGRAPHIC.

Alfanova and Raiskii. *Zavod. Lab.*, 1936, **5**, 1202–7.

Gazzi. *Chim. ital.*, 1934, **64**, 102.

Matveev. *Zavod. Lab.*, 1937, **6**, 456.

Schliessmann. *Arch. Eisenhüttenw.*, 1934, **8**, 159.

IN FERRO-TUNGSTEN.

Bogdanchenko. *Zavod. Lab.*, 1938, **7**, 1425.
(Alkimetric titration of WO_3 after decomposition in HF and HNO_3.)

Uranium

Uranium is sometimes to be found in tungsten steels. The contributions reflect a growing preference for volumetric methods in which the uranium is reduced to the quadrivalent state by zinc or amalgams and then titrated with permanganate or iodine, involving a preliminary removal of Fe, W, Mo, Cr, and V. The present writer favours isolation of the uranium by means of cupferron, which also precipitates several other elements; these may, however, be readily separated by re-precipitation with the uranium in the oxidised condition. The estimation is completed by conversion to U_3O_8, to the oxine complex, or to the yellow peruranate obtained with hydrogen peroxide and alkali carbonate.

METHODS.

Bennett. *J. Amer. Chem. Soc.*, 1934, **56**, 277.
(In ferrous ores; Hg-cathode separation, precipitation of Ti by cupferron, and titration with $KMnO_4$ after passing through Jones' reductor.)

Dymor and Molchanova. *Zavod. Lab.*, 1938, **7**, 653.
(Review of methods including those of Lundell, Hoffman and Bright and Cain.)

Ostroumov. *Zavod. Lab.*, 1935, **4**, 754.
(Duimov and Volodina's modification of Someya's method of reduction with amalgam and titration with $KMnO_4$.)

Panchenko. *J. Applied Chem.*, U.S.S.R., 1935, **8**, 361.
(Iodometric method.)

Strubl. *Collection Czechslov. Chem. Commun.*, 1938, **10**, 466.
(Polarographic estimation with dropping Hg-cathode.)

Vanadium

With few exceptions, the methods described are based on measured interchange between V_2O_4 and V_2O_5, usually by titration with ferrous ammonium sulphate or potassium permanganate. Even in the cold, reduction with the former takes place readily, and in the presence of oxidised diphenylamine sulphonate, the slightest excess of reagent furnishes a well-defined colour change. The use of this indicator is described by Willard and Young, in conjunction with the conversion of tungsten into soluble complex fluoride, thereby inhibiting the serious adsorption losses caused by tungstic oxide.

Rapid potentiometric determination of the end-point in titrations with ferrous or chromous compounds has been devised by Thanheiser and Dickens, and several investigators have introduced slight modifications. Reliable spectrographic technique is described.

In the colorimetric methods, photo-electric measurement is favoured. As an alternative to the peroxide reaction, with which titanium interferes, the yellow phosphovanodomolybdate may be formed.

VOLUMETRIC.

Andreev. *Zavod. Lab.*, 1938, **7**, 258.
(Titration with fuschin red or trypan red to obviate difficulties due to leuco compounds of indicators.)

Duimov and Volodina. *Zavod. Lab.*, 1933, **2**, No. 9, 25.
(Reduction with Hg–Bi using Ph_2NH and titration with $KMnO_4$.)

Farber. *Chem. Ztg.*, 1931, **55**, 691.
(Evaporation with HCl and H_2SO_4, followed by permanganate titration.)

Gutman and Mon'yakova. *Soobshcheniya Vsesoyuzrogo Ins. Metal*, 1931, Nos. 1 and 2, 66, 68.
(*a*) Treatment with dil. H_2SO_4 and determination of V in residue; (*b*) HCl - H_2SO_4 - H_3O_2 - $KMnO_4$.)

Khitarov. *Zavod. Lab.*, 1935, **4**, 491.
(Treatment with Na_2AsO_3 and Ph_2NH, oxidised, reduction with $Fe^{\cdot\cdot}$.)

Lur'e and Nekrasova. *Zavod. Lab.*, 1932, Nos. 8–9, 34–48; *Chem. Zentr.*, 1934, II. 3283.
(Titration with $Fe^{\cdot\cdot}$.)

Mon'yakova. *Repts. Central Inst. Metals* (Leningrad), 1934, No. 16, 197.
($(NH_4)_2S_2O_8$ - $KMnO_4$.)

Mukhina. *Zavod. Lab.*, 1939, **8**, 162.
(Solution in $HClO_4$ and removal of Cr as CrO_2Cl_2.)

Mukhina and Zolotereva. *Zavod. Lab.*, 1934, **3**, 784.
(Dissolved in $HClO_4$, oxidised in cold with $KMnO_4$, treated with $NaNO_2$, 5 g. CO (NH_2), 3 drops 1% Ph_2NH in H_2SO_4 and titrated with $Fe^{\cdot\cdot}$.)

Ostroumov. *Zavod. Lab.*, 1935, **4**, 754.
($(NH_4)_2S_2O_8$ method.)

Panchenko. *J. App. Chem.*, U.S.S.R. 1935, **8**, 361.
(Reduction to VO with Zn amalgam and iodometric titration.)

Reosoul. *Ing. chim.*, 1934, 18, 63.
(W removed, fumed with H_2SO_4-H_3PO_4 and titrated $KMnO_4$.)

Seuthe and Schaefer. *Arch. Eisenhüttenw.*, 1937, **10**, 549.
(Solvent consisting of one part $HClO_4$ and three parts HNO_3.)

Stepin. *Zavod. Lab.*, 1939, **8**, 1039.
(In cast irons and slags; *p*-phenylaminobenzoic acid preferred to *o*-phenanthroline.)

Tager. *Zavod. Lab.*, 1934, **3**, 369.
(Iodometric titration.)

Tashiro. *J. Chem. Soc.*, Japan, 1932, **53**, 13.
(Reduction with Zn amalgam and titration with iodate.)

Travers. *Bull. Assoc. Tech. Fonderie*, 1934, **8**, 383.
(Solution in $HClO_4$, Si and W removed, treated NH_4OH, then H_3PO_4.H_2SO_4 and H_2O_2, evaporated to fumes, and titrated with $KMnO_4$.)

Werz. *Z. anal. Chem.*, 1930, **81**, 448.
($(NH_4)_2S_2O_8$, $KMnO_4$, $H_2C_2O_4$, KI, $Na_2S_2O_3$.)

Werz. *Z. anal. Chem.*, 1931, **83**, 161.
(In iodometric method, 35 mins., boiling required to decompose excess $(NH_4)_2S_2O_8$.)

Willard and Young. (i) *Ind. Eng. Chem. Anal. ed.*, 1932, **4**, 187.
(Diphenylbenzidine as internal indicator in titration with Fe''.)

Willard and Young. (ii) *Ind. Eng. Chem. Anal. ed.*, 1933, **5**, 154.
(Diphenylamine sulphonic acid and oxidised diphenylamine as indicators for determination in alloy steels.)

Willard and Young. (iii) *Ind. Eng. Chem. Anal. ed.*, 1934, **6**, 48.
(o-phenanthroline-ferrous complex as indicator.)

POTENTIOMETRIC.

Blanken. *Chem. Weekblad*, 1932, **29**, 263, 384.
(Large excess of C_2H_5OH required in method of Thanheiser and Dickens. The $(NH_4)_2S_4O_8$-$KMnO_4$ process involves slight re-oxidation of V.)

Brintzinger and Rost. *Z. anal. Chem.*, 1939, **4**, 117.
(Reduction with $CrSO_4$.)

Dickens and Thanheiser. (i) *Mitt. K. W. Inst. Eisenfor.*, 1932, **14**, 169.
(In steels and ferro-vanadium; reduction of excess $KMnO_4$ with $H_2C_2O_4$ and titration with Fe''.)

Dickens and Thanheiser. (ii) *Mitt. K. W. Inst. Eisenfors.*, 1938, **20**, 35.
(Using Pt-electrode and $CrSO_4$.)

Fogel'son and Kalmykova. *Zavod. Lab.*, 1936, **5**, 1248, 1305.

Gutman and Mikeeva. *Soobshcheniya Vsesoyaznogo Inst. Metal*, 1931, Nos. 5 and 6, 73.
(In self-hardening steels; Fe'' titration.)

Gutman and Piradyan. *Repis. Central Inst. Metals*, 1934, No. 16, 190.
(In high-chromium steels, $KMnO_4$ titration.)

Heczko. *Angew-Chem.*, 1931, **44**, 992.
(Review; calomel cell disliked.)

Khlopin. *Zavod. Lab.*, 1936, **5**, 939.
(A polemic with Adamovich on the titration with ferrous salt.)

Khlopin and Pinskaya. *Zavod. Lab.*, 1937, **6**, 1272.
(In steels, cast irons, alloys and slags.)

Miloslavskii and Kuduish. *Zavod. Lab.*, 1935, **4**, 31.
(Review, with slightly modified procedure.)

Razuvaeva. *Zavod. Lab.*, 1935, **4**, 494.
(Thanheiser-Dickens method with refinements.)

Sosnovskii. *Domez*, 1934, No. 10, 57.
($(NH_4)_2S_2O_8$ oxidation and titration with Fe''.)

Thanheiser and Dickens. *Mitt. K. W. Inst. Eisenfor.*, 1931, **13**, 187.

Werz. *Z. anal. Chem.*, 1931, **86**, 335.
(In Fe-V by titration with ferrous salt.)

Zan'ko and Shlyakman. *Zavod. Lab.*, 1934, **3**, 777.
(Titration with $CrSO_4$.)

COLORIMETRIC.

(*a*) *Visual.*

Ducz. *Bull. Assoc. Tech. Fonderie*, 1934, **8**, 570.
(In titanium irons and steels by means of "blanks.")

(*b*) *Photometric.*

Bogatzki. *Arch. Eisenhüttenw*, 1939, **12**, 539.
(In tungsten steels; as yellow phosphovanadomolybdate.)

Davydov and Vaisberg. *Zavod. Lab.*, 1940, **9**, 715.
(Formation of blue phosphovanadomolybdate by $SnCl_2$ at 0·03–0·15 N—H_2SO_4.)

Pinsl. (i) *Arch. Eisenhüttenw.*, 1937, **11**, 293; *Angew. Chem.*, 1937, **50**, 115.
(With H_2O_2, using selective filters.)

Pinsl. (ii) *Giesserei*, 1940, **27**, 441.
(In alloyed pig iron and cast iron; in presence of Ti, and Mo, but not W; NaF used to suppress Fe colour.)

Somiya and Nakamira. *J. Soc. Ind.*, Japan, 1935, 38 (Supp. binding), 262.
(Titration method.)

POLAROGRAPHIC.

Thanheiser and Willems. *Mitt. K. W. Inst., Eisenfor.*, 1939, 21, 65; *Arch. Eisenhüttenw.*, 1939, **13**, 73.

SPECTROGRAPHIC.

Alekseev *et al.* *Zavod. Lab.*, 1938, **7**, 603.
(Alifanova-Raiskii method.)

Schliessman. *Arch. Eisenhüttenw.*, 1934, **8**, 159.
(Using two prisms.)

Wilken. *Arch. Eisenhüttenw.*, 1938, **12**, 133–40.

MISCELLANEOUS.

Parks and Prebluda. *J. Amer. Chem. Soc.*, 1935, **57**, 1676.
(Hexamine-cobaltic compounds in the gravimetric estimation of vanadium.)

Somiya and Nakamira. *J. Soc. Chem. Ind.*, Japan, 1935, 38 (Supp. binding), 262.
(Photometric titration; in high-speed steel with Cu-Cu_2O cell.)

Wada and Issi. *Bull. Inst. Phys. Chem. Research*, Tokyo, 1938, **17**, 434.
(In Fe-Cr; ether separation of Cr as chromate and titration with $FeSO_4$.)

Zinc

Although zinc is not normally used as an alloying constituent, small percentages of the element are sometimes introduced through scrap or ferro-alloys. In addition, the quantitative examination of zinc coatings may be required. An important precaution is the avoidance of rubber (which usually contains large proportions of zinc oxide) in detaching precipitates, etc. In the hydrogen sulphide precipitation, sulphate solutions are preferable; a fast stream is essential and the degree of acidity should not exceed 0·1 N. Contaminating sulphides may be removed by passing the hydrogen sulphide at a higher acid-concentration. When completed gravimetrically, it is customary to weigh as the oxide or phosphate; when the former is chosen, the temperature of ignition should not exceed 900° C. Titration with ferro-cyanide is favoured by several contributors.

IN IRON AND STEEL.

Bright. *Bur. Stand. J. Res.*, 1934, **12**, 383–9.
(Separation from iron by Rothe ether method in order to facilitate conventional sulphide procedure.)

Deiner and Kaiser. *Z. Elektrochem.*, 1935, **41**, 153.
(In electrolytic methods, best results obtained with copper cathode in cyanide bath.)

Fainberg and Troitzkaya. *Zavod. Lab.*, 1935, **4**, 104.
(In Lang's method, the KHF_2—used to form FeF_6—is controlled by testing with 5% KCNS.)

Hills. *Ind. Eng. Chem., Anal. ed.*, 1933, **5**, 201.
(Small amounts by precipitation by H_2S from citric-citrate medium and subsequent titration with $K_4Fe(CN_6)$.)

Kato. *J. Chem. Soc.*, Japan, 1934, **55**, 293.
(Precipitation of ZnS at *p*H2·3–2·5, at which very little co-precipitation of FeS.)

Kruger. *Z. anal Chem.*, 1933, **93**, 422.
(Precipitation of ZnS from solution containing 1·5–2·0 ml. of HCl per 100 ml. at 70° C. after preliminary reduction of iron to prevent increase in acidity.)

Lang and Reifer. *Z. anal Chem.*, 1933, **93**, 161–72.
(Titration with $Na_2S_2O_3$ in the presence of HI and $K_3Fe(CN_6)$.)

Mukhina. *Zavod. Lab.*, 1935, **4**, 150.
(Formation of pyridine-thiocyanate complex.)

ZINC COATINGS.

Azzarelloekal. *Riv. ferrovic. ital.*, 1933, **43**, 267–89.
(Measurement of H_2SO_4 in special apparatus and titration of Fe'' with $KMnO_4$.)

Nash. *Analyst*, 1936, **61**, 540.
(The HCl-$SbCl_3$ procedure is the quickest and most widely used, but the H_2SO_4-$KMnO_4$ method is preferable.)

Vallmer. *Chem. Fabrick*, 1938, 465.
(Extraction with alkaline solutions.)

IN IRON ORES.

Brossonov. *Zavod. Lab.*, 1935, **4**, 12.
(In iron ores containing copper; based on the insolubility of CuS in 1 : 9 H_2SO_4, with which the combined sulphides are treated, the zinc then being determined by electrolysis.)

Ladurgina and Lakhanova. *Zavod. Lab.*, 1935, **4**, 17.
(In iron ores, separation as ZnS and ferrocyanide titration using NH_4—molybdate as external indicator.)

Zirconium

The estimation of zirconium in ferrous metals has been considerably simplified by the introduction of various arsenical precipitants, of which the propyl compound is outstanding. When selenious acid is used, a preliminary ether separation is advisable. Although the ignited phosphate does not strictly comply with the pyrophosphate formula, the zirconium content is consistent.

Chandelle. *Bull. soc. Chin., Belg.*, 1937, **46**, 423.
(In Fe-Zr by precipitation with disodium methylarsenate.)

Cunningham and Price. *Ind. Eng. Chem. Anal., ed.* 1931, **3**, 105 1933, **5**, 334.
(In plain carbon and alloy steels.)

Geist and Chandler. *Ind. Eng. Chem. Anal. ed.*, 1937, **9**, 169.
(Precipitation with *n*-propylarsonic acid, a very satisfactory procedure with which Ti, Al, Cr, Co, Ni, U, V, Th, Mo and W do not interfere.)

Hayes and Jones. *Ind. Eng. Chem. Anal. ed.*, 1941, **13**, 603.
(Colouration produced with *p*-dimethylaminophenylazobenzene-arsonic acid.)

Kar. *Metals and Alloys*, 1935, **6**, 156.
(Electrolytic method for chromium steels.)

Klinger and Schliessmann. *Arch. Eisenhüttenw.*, 1933, **7**, 113.
(In iron, steel and ferro-alloys by means of phenyl-arsonic acid (after ether separation) and ignition to ZrO_2.)

Simpson and Schumb. *Ind. Eng. Chem. Anal. ed.*, 1933, **5**, 40.
(Precipitation from dilute HCl solutions containing H_2O_2 with selenious acid and ignition to ZrO_2.)

Stephen, Simpson and Schumb. *Ind. Eng. Chem. Anal., ed.*, 1933, **5**, 211.
(Precipitated zirconium selenide converted into phosphate.)

Tzinberg. *Zavod. Lab.*, 1935, **4**, 735.
(In Fe-Zr by means of oxine.)

Reviews of Current Literature

Essential Metallurgy for Engineers

OPINIONS vary considerably on what constitutes essential information on metallurgy useful to engineers, but few will dispute the real need for a wider knowledge of metallurgy by engineers. A surprisingly large number of engineers continue to embrace the wide range of metallic materials, as cast iron, steel, brass and bronze, aluminium and magnesium, and they make little attempt to distinguish between the many types within a particular range. On the other hand, many are frankly confused by the tremendous range of materials now available, and seek basic information upon which they can acquire knowledge of the materials they use. This book has been designed to provide the required information, and it is apparent that the author has given very careful thought to the subject before proceeding with his venture.

That the author has very definite ideas on the subject is not difficult to appreciate from the method of presentation. He believes that unless an engineer approaches his material from the same angle as the metallurgists who produced it, he is pretty certain to be disgusted and defeated. Blindly to attempt to follow mere instructions is equally to invite disaster in far too great a number of cases. Seeing eye to eye in these matters with the producers is likely to make all the difference to engineers between success and failure.

It is physical metallurgy with which the engineer is primarily concerned, and the author proceeds to answer the question given in the introduction, viz.: "By what internal mechanism are the metals naturally possessed of the mechanical properties—strength, ductility, and so forth; and how may metallic materials deliberately be endowed with all those properties to a high degree?" His method of presentation is novel, but it is informative and, moreover, it is convincing. Dealing with fundamentals in such a way gives the engineer the basic facts upon which he can build his knowledge of metals and alloys.

The first six chapters deal with the internal structure by which plain metals exhibit their mechanical properties, and show how the mechanical properties may be developed in certain definite ways. Attention is drawn to the simplest metal of all—the liquid metal; to the next in simplicity—the metal crystallised as one single crystal; to the metal in the commonest known form—the polycrystalline mass; and, finally, to the polycrystalline mass of metal deformed at temperatures below the annealing temperatures, and which contains "amorphous" metal inside the grains as a result of disruption and chaos at the gliding planes. The methods of modifying the properties of metals considered are grain refining, cold work, alloying to form a solid solution, and alloying to form a solid solution at higher temperatures from which a compound may be precipitated at the lower temperatures.

The author then proceeds to discuss mechanical properties, to describe the metallurgist's technique, and then directs attention to the equilibrium diagram. Subsequent chapters deal with the properties of straight carbon steels; case-hardening; alloy steels; the non-ferrous metals and alloys, including copper-, aluminium- and magnesium-base alloys; heat-treatment for optimum properties; microscopic structures and properties; alloy specifications and markings; and corrosion. An interesting concluding chapter is entitled "Curative measures in general," and is concerned with the effect on metals of accidental fire, of occasional gross overload, and of fatigue in a burnt or corroded state, on which it is necessary to assess the possibilities of repair. A useful glossary and an index are included.

The book is really an intensified course of instruction in metallurgy for the engineer, and the subject is admirably presented by an experienced and competent authority. Engineers will not find this book easy to read, but a careful study of it will amply repay such labour as that may involve. Its 155 pages are full of meat, and, apart from engineers, metallurgists will be intrigued with the method of presentation and find the book of more than usual interest. In these times, and having in mind the surprising amount of information contained in its pages, the price is low.

By A. C. Vivian, B.A., D.Sc., A.R.S.M., with an introduction by Professor R. S. Hulton, M.A. Published by Sir Isaac Pitman and Sons, Ltd., Parker Street, Kingsway, London, W.C. 2. Price 8s. 6d. net.

Magnetic Crack Detection

IN addition to normal mechanical tests to which materials are subjected to check all relevant qualities that have a direct bearing on the application of a particular material, many non-destructive tests are applied to components. These latter methods are designed to determine the soundness of the material of which the component is composed. Of these methods, crack-detection of ferrous materials by magnetic means is an important example, and since published information on this aspect of non-destructive testing is somewhat limited, this small book, dealing with the practical side of magnetic crack detection, should prove very useful.

Crack detection by magnetic means is not new, but the introduction of improved methods of magnetisation, together with a comparatively new technique, have tended to produce, in many cases, misleading results, and difficulties have arisen in everyday practice which have caused delays that could have been avoided had information been readily available. The author has been intimately associated with this method for several years, during which time it has been his job to overcome difficulties encountered in its application. At the request of his many friends in inspection departments, he has presented in this book an outline of the working principles of this method, together with practical information on the use of the appropriate equipment, and of the interpretation of the results obtained. The information, though condensed in about sixty pages, is presented in a simple and readily understood form, and should be a great help to all engaged in the inspection of ferrous components.

By G. B. Young. Published by Charles Griffin and Co. Ltd., 42, Drury Lane, London, W.C. 2. Price 2s. 6d., net.

Temperature Control

HEAT plays an essential part in the production and fabrication of many materials from the initial stages to the manufacture of the finished product or component. In many applications it must be controlled within very fine limits, notably in the heat-treatment of metals and alloys in chemical processes of various kinds; the measurement of physical constants, such as refractive indices, also call for temperatures within narrowly defined limits. Certainly the present trend is towards the more accurate use of heat to meet the exacting modern demands, and it is not surprising that, in recent years, much attention has been given to temperature control.

Some of the methods to effect temperature control are correlated in this book, and although the author does not claim that his treatment of the subject is exhaustive, he has managed to include a considerable amount of information that should form a useful guide rather than a solution to every control problem. Uniformity of temperature is now so necessary in a multiplicity of operations that control has become essential where this can be satisfactorily effected, and many methods have been devised that meet the requirements of particular operations.

The author first deals with general considerations for temperature control, and then discusses liquid expansion controls; vapour baths and vapour-pressure methods; metal expansion controls; gas-expansion controls; change of resistance with temperature control; temperature control, utilising the photo-electric effect; thermo-electric current control; temperature control as applied to scientific instruments; liquid and air baths. Included also are four appendices which are concerned with relays; galvanometers; the Wade and Merriman pressure manostat; and thermal constants, densities, electromotive force of standard cells, resistivity of some common metals, nickel-chromium resistance wire and taps. Thus, it will be appreciated, the subject is presented in a comprehensive manner.

The various methods are ably discussed, and there can be no doubt that the information given will be of great service to all workers who have need of some form of constant temperature control within the range of 0° C. to about 1,500° C. No attempt has been made to deal with very low temperatures.

By A. J. Ansley. Published by Chapman and Hall, Ltd. 11, Henrietta Street, London, W.C. 2. Price 13s. 6d.

The Mechanical Testing of Aluminium and Aluminium Alloy Products, and its Bearing on Working Properties

THE testing of materials, whether it be of a commercial or research nature, is conducted with the object of ascertaining data regarding their physical and mechanical properties, and it is nowadays regarded as a part of inspection procedure, and new firms would consider purchasing, or manufacturers selling, materials which have not been so tested. It is an accurate means of maintaining a high standard of quality and consistency, the tests for each material being arranged as far as possible to check all relevant qualities, bearing in mind the ultimate application.

Where light aluminium alloys are concerned, the final applications may be so varied as the spinning of saucepans from commercially pure aluminium sheet, or the manufacture of airscrew blades from extruded strong alloy rod, but in any event the uniformity and quality will be established by suitable tests. The particular properties for which an alloy is examined will be dependent upon several factors, such as:—

(1) The importance of the use to which the metal is put, and whether the maximum stresses it is capable of carrying with safety are required to be accurately known, as in aircraft work.

(2) The shape and style of product. For instance, in the case of sand or die castings for commercial use, non-destructive testing by the determination of Brinell hardness may be used, the quality of the metal being further checked by tests to destruction of representative separately cast specimens. It should be noted here that the results obtained from separately cast test-bars are not necessarily the same as would be shown by specimens cut from the casting, but they give an indication of the quality of the metal.

(3) Type of operation used. Commercial-quality aluminium sheet, for use in presswork and spinning, for example, requires fine crystal size, good elongation and minimum directionality of grain, these being more important than tensile strength. An Erichsen cupping test is normally used here.

The above is an introduction to a very careful consideration of mechanical testing and its bearing on the working properties of aluminium and its alloys published in a recent Bulletin of the Northern Aluminium Co., Ltd. It deals with the various forms of test, and describes the general procedure and representative testing machines used. A valuable section is that which deals with the relation of mechanical properties to the working properties. Under this heading are considered deep pressing, drawing and spinning; bending and flanging; machining and polishing; cold forging, heading and upsetting; punching and shearing. Copies may be obtained free of charge on application to Research and Development Department, Northern Aluminium Co., Ltd., Banbury, Oxfordshire.

Electrodepositors' Technical Society

Following representations made by the above Society to the D.T.D. of the Ministry of Aircraft Production regarding the desirability of close liaison between the metal-finishing industry and the D.T.D. in the formulation of metal-finishing specifications, a Committee has now been set up by the D.T.D. on which the Society is fully represented to investigate all technical matters relating to electrodeposition processes. This Committee will meet periodically and is already exploring the D.T.D. specifications with a view to their being revised in line with modern practice.

Members of this Society who wish to raise any technical points relating to metal-finishing specifications which they are called on to fulfil are asked to communicate with the Hon. Secretary, Dr. S. Wernick. Information will be particularly welcomed on real difficulties which are being encountered in practice in carrying out D.T.D. specifications.

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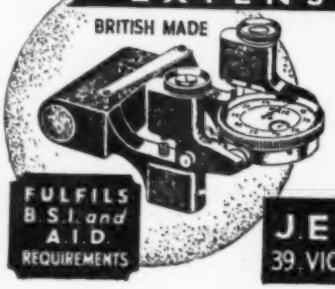

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